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Piloting the use of accelerometry devices to capture energy expenditure in agricultural and rural livelihoods: Protocols and findings from northern Ghana

Giacomo Zanello[a,*], C.S. Srinivasan[a], Paul Nkegbe[b]

[a] School of Agriculture, Policy, and Development, University of Reading, United Kingdom
[b] University for Development Studies, Ghana

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ABSTRACT

In this study we report on the protocols adopted and the findings from a pilot study in northern Ghana involving 40 respondents wearing accelerometry devices for a week. We show how integrating energy expenditure data from wearable accelerometry devices with data on activity and time-use can provide a window into agricultural and rural livelihoods in developing country contexts that has not been previously available for empirical research. Our findings confirm some of the stylised facts of agricultural and rural livelihoods, but the study also provides several new insights that come from the triangulation of energy expenditure, time use, and activity data. We report findings and explore the potential applications of using accelerometry devices for a better understanding of agriculture-nutrition linkages in developing countries.

1. Introduction

The limited uptake of agricultural innovations with proven productivity-enhancing potential and the translation of productivity increases into improvements in nutrition are two major challenges facing Low and Middle Income Countries (LMICs) (Gillespie and Kadiyala, 2012; Global Panel, 2015; IFPRI, 2015; Turner et al., 2013). The human energy expenditure patterns associated with agricultural and livelihood activities can be expected to have an important influence on the uptake of productivity-enhancing agricultural innovations and their nutrition impacts on the rural population in developing countries (Johnston et al., 2015). Assessments of the impacts of agricultural interventions in LMICs have been largely confined to examining productivity increases. However, it has been recognised that the uptake of innovations may be significantly influenced by human energy expenditure and time-use patterns linked to the use of innovations. Further, the impact of increased productivity on nutrition for individual members of agricultural households may be mediated by gender-differentiated intra-household labour and consumption allocation decisions (Johnston et al., 2015). Incorporating the human energy expenditure dimension in analyses of the uptake of agricultural innovations and their nutrition impacts has been constrained by a lack of reliable robust empirical measurement of energy expenditure associated with agricultural activities in free-living populations.

The Doubly-Labelled-Water (DLW) method has been the standard method used to capture energy expenditure levels of free-living humans. However, this method requires respondents to be brought into an experimental facility and does not allow study of a large and representative samples. Advances in accelerometry technology offer the opportunity to scale-up empirical measurement of energy expenditure profiles in developing countries, and the pilot study described in this paper takes advantage of this to generate rigorous energy expenditure profiles associated with agricultural and livelihood activities. Accelerometry devices (tri-axial accelerometers) are small watch-like devices worn with a clip or belt, suitable for constant wear, which continuously record the movement of the wearers along the three axes. The movement data can be translated into the energy expenditure associated with physical activities. Recent advances have led to development of rugged wearable accelerometry devices suitable for use in the context of rural/agricultural occupations. These allow non-intrusive data collection, requiring no user inputs, facilitating scaled-up empirical measurement of energy expenditure in rural free-living populations.

In this paper we report lessons learnt from using accelerometry devices in rural areas in a developing country context. We also develop a methodological framework in which energy expenditure data from accelerometry devices is integrated with information from activity and time-use questionnaires administered to respondents to

* Correspondence to: School of Agriculture, Policy and Development, University of Reading, Reading, United Kingdom.
E-mail address: g.zanello@reading.ac.uk (G. Zanello).

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build energy expenditure profiles associated with agricultural and livelihood activities. We report our experience with a pilot study in rural Ghana, provide preliminary results and highlight potential future applications.

2. Scientific justification of capturing energy expenditure in agricultural and rural livelihoods

Undernutrition remains a significant developmental challenge in the developing world with one in four children under the age of five suffering from stunting or chronic undernutrition (Black et al., 2013). The stubborn persistence of undernutrition in spite of the remarkable improvements in agricultural productivity and production in developing countries over the last five decades has generated considerable policy interest in making agriculture 'nutrition-sensitive', i.e. in designing agricultural interventions that lead to improved nutritional outcomes. The impact of productivity-enhancing agricultural interventions on nutrition and health outcomes in developing countries operates through complex pathways that are not well understood (Dangour et al., 2013; Headey et al., 2012). In many developing countries, there appears to be a perplexing disconnect between agricultural productivity growth and expected improvements in nutrition status (Meeker and Haddad, 2013; Gillespie and Kadiyala, 2012). Exploring and delineating agriculture-nutrition linkages is a priority area for research (Turner et al., 2013).

Productivity-enhancing agricultural interventions impact the calorie deficits of the undernourished via their effects on energy intakes and energy expenditure. At the level of the individual, these effects are further mediated by intra-household allocations of consumption and labour. Intra-household allocations of time, labour and consumption have been recognised as significant determinants of the adoption of productivity-enhancing agricultural innovations and their impact on the nutritional status of individual household members (Blackden and Wodon, 2006; Haddad et al., 1997; Ilahi, 2000). Gender and age-related differentiation in intra-household allocation decisions have been observed to have an important role in explaining the nutrition impacts of productivity-enhancing innovations in developing country contexts (Johnston et al., 2015). A key impact pathway to nutrition is the effect of innovations on energy expenditure and energy intakes of individuals, mediated by intra-household allocation decisions. However, reliable and accurate empirical measurement of energy expenditure and intake impacts of agricultural productivity-enhancing innovations at the level of the individual remains challenging. This research will take advantage of advances in accelerometry technologies that make it possible for scaled-up empirical measurement of energy expenditure of the rural population in developing countries.

A substantial body of literature has examined intra-household allocation decisions related to consumption. Unitary household models explaining consumption behaviour have been replaced by models of household behaviour with outcomes being decided through a complex bargaining process (Doss, 2013). Availability of data on food consumption at the level of the individual member of the household in developing countries is still extremely limited, which explains the reliance on indirect approaches to assessing equity in household consumption (Lise and Seitz, 2011). Most of the empirical studies on intra-household time use and labour allocation rely on self-reported activity diaries or profiles or on observational data. Translation of activity profiles or observational data into accurate estimates of energy expenditure remains problematic because such data do not capture the variability and heterogeneity of activity intensity over time intervals. The energy expenditure dimension associated with productivity-enhancing agricultural interventions and its implications for nutrition outcomes for individuals within a household are, therefore, still not well understood and remain a black box.

3. Literature review

3.1. Physical activity amongst farmers in low-income countries

Most of the research on studying nutrition in low and middle income countries has predominantly focused on changes in diets while changes in physical activities have been largely neglected (Popkin, 2006). Dufour and Piperata (2008) identified only 26 studies reporting physical activity levels (PAL) of rural populations in low-income countries. PAL provides a more suitable measure of physical effort compared to total energy expenditure (TEE) because it corrects for body size, allowing comparison across gender and body-types. Most of these studies have used the so-called factorial method, which infers the total energy expenditure of an individual based on activity diaries. The time spent on each activity is multiplied by the average energy intensity of the activity estimated by indirect calorimetry methods (Durnin and Brockway, 1959). Other studies have used the DLW method and heart rate monitors (HRM) which provide energy expenditure estimates with accuracy within 3–5% and 6% respectively of direct calorimetry estimates (Ceesay et al., 1989; Norgan, 1996).

A review of empirical studies shows an average PAL of males and females in agricultural settings of 1.9 and 1.7 respectively, which is at the high end of what is considered to be "moderate" activity level (FAO/WHO/UNU, 2004). However, significant variations have been found across geographical locations and seasons. Studies of male farmers in Burkina Faso (Bleiberg et al., 1981), Cameroon (Pasquet and Koppert, 1993), and India (Edmundson and Edmundson, 1989) show light activity level ($1.4 < PAL < 1.69$), while vigorous activity levels ($PAL > 2$) were found in Philippines (Guzman et al., 1974), Gambia (Heini et al., 1996), and Thailand (Murayama and Ohtsuka, 1999). For females, vigorous activity levels were found only in Bangladesh amongst tea pickers (Vinoy et al., 2000). A few studies have collected data across different agricultural seasons revealing the diversity of physical activity levels across seasons. Greater differences across seasons were found in environments with a strong wet-dry seasonality where people rely on harvest of cereals for their subsistence. For example, in Myanmar the PAL of farmers varies from a vigorous activity level (2.51) during the peak season to a light activity level (1.41) post-harvest. Females PALs tend to be more consistent throughout the year, possibly because of their involvement in domestic chores and children care that is constant (Dufour and Piperata, 2008).

The differences in PAL by gender and seasons are largely determined by the different activities that are carried out. Vaz et al. (2005) compiled an extensive database of energy costs of specified activities, some of which are typical of rural populations in low-income contexts. For each activity, energy cost of the activity (kcal min^{-1}) and physical activity ratios (PARs) computed as the energy cost of the activity divided by BMR were reported. Table 1 reports the information for agricultural related activities. There is a huge variation in energy cost of activities by crops and technologies. For example, estimates of energy costs of crop harvesting range from 1145 cal/hour recorded amongst groundnuts male farmers in Gambia to 288 cal/hour for rice growers. The energy costs of other activities, such as hoeing and ploughing, are less crop specific. These activities have more consistent energy requirements across farm households using similar technology. Such estimates are informative to compare the relative energy cost and PAL of activities. However, they do not take into account periods of rest and pauses during the performance of the activity and, therefore, likely to overestimate energy expenditure.

3.2. Use of accelerometry technology in low-income context

Scientific (physiological) empirical measurement of energy expenditure profiles in developing countries (e.g., using the "gold-standard" DLW method and indirect calorimetry methods) has been hampered by the high cost and difficulty in applying standard methods and protocols

Table 1
Total calories expenditure for selected agricultural activities (Vaz et al., 2005).

Activity	n	G	E	PAR	EE	Country	Study
Digging		M	6.4	5.71	2193	Iran	Brun et al. (1979)
Digging (bending)	21	M	4.05	4.67	1135	Gambia	Lawrence et al. (1985)
Digging (channels for irrigation)	6	M	3.25	3.53	688	India	Ramana Murthy and Belavady (1966)
Harvesting (cotton)		M	3.6	3.21	693	Iran	Brun et al. (1979)
Harvesting rice (bending)	26	F	3.22	3.93	759	China	Brun (1992)
Harvesting (sorghum)	6	M	2.4	2.15	310	Burkina-Faso	Brun et al. (1981)
Harvesting	10	M	3.8	4.08	930	India	Ramana Murthy and Belavady (1966)
Harvesting (groundnuts)	17	M	4.07	4.69	1145	Gambia	Lawrence et al. (1985)
Harvesting (manioc)	8	M	2.48	2.83	421	Brazil	Dufour (1984)
Harvesting (rice)	19	M	2.04	2.35	288	Gambia	Lawrence et al. (1985)
Hoeing	11	M	5.1	4.57	1398	Burkina-Faso	Brun et al. (1981)
Hoeing	6	M	4.57	4.34	1190	Multi-country	Phillips (1954)
Hoeing	11	W	4.3	4.75	1226	Burkina-Faso	Bleiberg et al. (1981)
Hoeing (push hoe)	12	M	4.66	4.87	1362	India	Ramana Murthy and Belavady (1966)
Ploughing	11	M	5.48	5.79	1904	India	Ramana Murthy and Belavady (1966)
Ploughing	10	M	5.45	5.17	1691	Bangladesh	Fariduddin et al. (1975)
Sowing	4	W	3.9	4.31	1009	Burkina-Faso	Bleiberg et al. (1980)
Sowing	5	M	3.9	3.5	819	Burkina-Faso	Brun et al. (1981)
Sowing (planting manioc)	6	M	3.18	3.64	695	Brazil	Dufour (1984)
Weeding	12	F	2.3	2.66	367	Papua New Guinea	Norgan et al. (1974)
Weeding		M	5.2	4.64	1448	Iran	Brun et al. (1979)
Weeding (groundnuts)	25	M	2.81	3.24	546	Gambia	Lawrence et al. (1985)
Weeding (rice)	45	M	1.98	2.28	271	Gambia	Lawrence et al. (1985)
Winnowing		M	4	3.57	857	Iran	Brun et al. (1979)

Note: n: Sample size; G: Gender; E: Energy cost of activity (kcal/min^{-1}); PAR = E/BMR; EE: Total Energy Expenditure for one hour of activity.

in these settings to free-living populations (MRC, 2013; Singh et al., 1989; Speakman, 1998). DLW is difficult to implement in free living populations as it involves the consumption of a carefully controlled amount of DLW and repeated collection of urine samples over a period of 10 days (Singh et al., 1989). Similarly, indirect calorimetry methods are also difficult to apply because these require respondents to be brought to laboratory or hospital facilities for extended periods of time (MRC, 2013). Given these limitations, several studies of physical activity patterns of subsistence farming population have used time allocation data. While such methods can be adapted to most environments, they can underestimate energy expenditure, especially at high levels of physical activity (Leonard et al., 1997; Spurr et al., 1996). Recent advances in technology allow the use of wearable accelerometry devices to capture energy expenditures. Energy expenditure data from accelerometry devices have been validated against data from DLW and heart monitors in free-living adult population (Dugas et al., 2010; Plasqui et al., 2013; Plasqui and Westerterp, 2007; Warren et al., 2010), yet their use in agriculture settings has been limited.

Advances in accelerometry technology, development of algorithms to extract behavioural/activity-related information from accelerometry data, and associated software for management of the large volumes of data generated by accelerometry based devices, offer the prospect of scaled-up empirical measurement of energy expenditure profiles in developing countries. Accelerometry based devices are being extensively used in surveillance and intervention studies in health (Matthews et al., 2012). Moreover, these advances in technology have allowed the development of rugged devices suitable for use in the context of rural/agricultural occupations, and which enable non-intrusive data collection, requiring no user inputs (other than compliance in wearing these devices).

In recent years a few studies have attempted to use accelerometry devices to assess energy expenditure from physical activity in sub-Saharan Africa. Assah et al. (2009) validated the use of accelerometry devices to collect data on energy expenditure of urban and rural participants to explore changing patterns of physical activity associated with increasing urbanisation in Cameroon. Results from a larger follow-up study of 544 participants confirmed that rural dwellers were significantly more active than their urban counterparts (Assah et al., 2015). In an earlier pilot project carried out in the Gambia, Reiches et al. (2009) tested the efficacy of accelerometers against heart rate monitors for measuring energy expenditure amongst rural women. Results indicated that an accelerometer worn on the hip was as effective as heart rate monitoring in measuring energy expenditure. A validation sub-study of the World Health Organization's 'Study on global AGEing and adult health' (SAGE), used accelerometer devices to validate self-reported physical activity reliability in 198 adults in Rajasthan (India). Accelerometry technology has been also used to record the physical activity of indigenous populations. Madimenos et al. (2011) investigated gender differences in activity patterns and the effects of reproductive status on activity of Shuar adults, an Ecuadorian forager-horticulturalist population. Other small-scale studies have used accelerometry devices to investigate the water turnover, physical activity and body composition among women in Kenya (Keino et al., 2014); physical activity in children and adolescents from a rural community in Mozambique (Prista et al., 2009) and school children and adolescents in India (Corder et al., 2007; Krishnaveni et al., 2009).

3.3. Time use and energy expenditure

Matching energy expenditures with activities provides a better understanding of the energy requirements. Vaz et al. (2005) show not only the different energy requirements of various agricultural activities but also how similar activities have different requirements based on crops and technologies. While the studies reviewed illustrate the use of accelerometry devices in low-income settings, they seldom relate energy expenditure to the activities carried out by the participants. Some studies using the DLW method have attempted to match energy expenditure to activities. For example, to explore potential differences in the intra-seasonal allocation of agricultural labour within an agro-pastoral community of the Bolivian Andes, Kashiwazaki et al. (2009) adopted direct observation of participants to compile individual diaries of activities. Other studies assessing human energy expenditures in rural contexts have adopted direct observation to record the time spent on different activities, usually for the waking day for 24 h (Brun et al., 1979; de Guzman Ma et al., 1984; Dufour, 1984) or 48 h (Bleiberg et al., 1980; Brun et al., 1981). Direct observation is considered the golden standard to capture time use in contexts in which daily activities are not scheduled by the clock. However, direct observation is still not feasible for longer periods of time (typically greater than 48 h) or for larger samples (UNSD, 2005). Antonopoulos and Hirway (2009) review the recent evidence of time use surveys in low-income countries and provide a solid platform to overcome the limitation embedded in direct observation without losing accuracy. Face-to-face interview recording time use in 24-h time diaries mitigates potential low level of literacy amongst respondents and enumerators are able to estimate and contextualise the sequence of events linking to major common events (e.g. sunrise, lunch, sunset) based on a narrative. In addition, longer duration time-slots (e.g. 1-h) mitigate recall errors that smaller slots (e.g. 15 min) are more prone to. Still, some limitations persists, such as identifying simultaneous activities and the detailed of activities reported.

4. Accelerometry devices

In developed countries, the commercial development of accelerometry and sensor based devices has brought about a boom in consumer-friendly activity monitoring devices for personal use. The rapid growth in the market for products such as Microsoft Band, Jawbone Up, Fitbit and a wide range of other brands bears testimony to the popularity of these products. The conversion of raw accelerometry data into aggregate measures of activity intensity or energy expenditure is technically challenging. In commercial (consumer) devices, these conversions are made through manufacturers' proprietary algorithms that are not in the public domain and access to raw accelerometry data from these devices is quite limited. We therefore used a series of ActiGraph accelerometer devices model GT3X+ that are tailored for research applications and allow access to raw accelerometry, with proprietary software support for data management and analysis. The ActiGraph GT3X+ device is a tri-axial accelerometer, which provides the end user with raw data on movement along the three axes. The advantages of this device are that it is portable, non-intrusive and waterproof, and suitable for 24 h continuous use in free living populations. Using an elastic belt, the unit is worn on the waist, positioned over their right iliac crest. The unit has adequate memory to store up to 30 days data depending on the sampling frequency (100 Hz is the maximum frequency) and has a battery life of 15 days to one month. Once the device is initialised using a PC and the respondent's characteristics entered (identification name, weight, height, gender, and ethnicity), it continuously tracks and stores activity information whether or not it is worn until the battery lasts or the memory is exhausted.

The reliability and validity of ActiGraph devices have been extensively assessed (Santos-Lozano et al., 2013; Sasaki et al., 2011) and these devices have been used in multiple studies involving free-living humans in various settings (Keino et al., 2014; Pawlowski et al., 2016; Sartini et al., 2015). ActiGraph devices are also being used in large scale collection of physical activity data, e.g. UK's National Diet and Nutrition Survey (NDNS), USA's National Health and Nutrition Examination Survey (NHANES), and USA's Women's Health Study. The development of energy expenditure profiles require the accelerometry data to be linked to the activity profile of the wearer. This was done (as explained below) through an activity profile questionnaire that was administered daily (to facilitate more accurate recall) to the respondents wearing the devices by trained enumerators within the community.

5. Study protocol: Design, data collection, and methods

The data collection took place in the Wa Municipality (Upper West Region in northern Ghana) during 8 weeks from July to August 2016. Every week, a list of all the households living in a chosen community was compiled with the input of the village assemblyman. From the list, two or three households were then randomly selected and approached to take part in the study. Except in one instance in which an individual selected got replaced on the recommendations of community leaders (because they felt strongly that person would not cooperate), all selected households agreed and indeed participated fully in the research. To provide a greater heterogeneity in the sample, every week households were selected from a different community within the Municipality.[1]

The study design aimed to integrate energy expenditure and movement data from accelerometry devices worn by respondents from rural agricultural households with time use data from daily physical activity questionnaires to develop reliable and robust energy expenditure patterns associated with a range of agricultural and rural livelihood activities.

5.1. Sample size and instruments

The sample included data from 40 economically active individuals (20 males and 20 females between the age of 16–64 years old) wearing accelerometry devices for 5 days each. Energy expenditure and food consumption data were, therefore, collected for a total of 200 person days and hourly activity data were collected for 4800 h. The data collection lasted 8 weeks during which 5 accelerometer devices were deployed simultaneously. Each week, in addition to data derived from the accelerometry devices, data were also collected through the administration of three questionnaires over 6 days:

Day 1. An initial household questionnaire was administered to the households aimed at capturing information on: household composition, dwelling characteristics, employment and labour force activities, land and agriculture, livestock, assets ownership, weekly food consumption based on food frequency and consumption habits, decision-making in the household, access to infrastructure.

Day 1. Within each household, one man and one woman were selected to wear an accelerometry device for a week (5 days) and to have a daily interview. The initial individual questionnaire collected information on anthropometrics (height and weight), general health, and individual food consumption. Anthropometric measures were recorded based on the guidelines recommended in Lohman et al. (1992).

Day 2–6. Each respondent wearing the accelerometry device was interviewed daily for 5 days. The individual daily questionnaire included a 24-h recall of sequential time allocation for different activities and individual food consumption. Time allocation activities were recorded following the instruments used to construct the Women's Empowerment in Agriculture Index (IFPRI, 2012) and administered following the guidelines in Antonopoulos and Hirway (2009) (1-h slots and free text to record the activity), while individual portion sizes and food intakes were recorded using the methodology outlined in Gibson and Ferguson (2008).

5.2. Data collection

Data collection was carried out by a team of two enumerators (a male and a female) supervised by a survey coordinator and managed by one of the study investigators. We deployed five accelerometer devices simultaneously in the field over eight rounds of one week each. The weekly survey design is represented in Fig. 1. In each round, on Monday the enumerators visited a community and randomly selected two households (from a household list provided by contact person(s) who were mostly community leaders). To capture intra-household variation in energy expenditure and time allocation by gender, from the initial household survey, two or three individuals (males and females) were selected in the households to wear the accelerometry device and an initial individual survey was administered to them. Enumerators

[1] The selected communities were: Loho, Piisi, Kunfabiala, Kperisi, Kpongpaala, Kpongu, Nakore, Siiriyiri (see Appendix A).

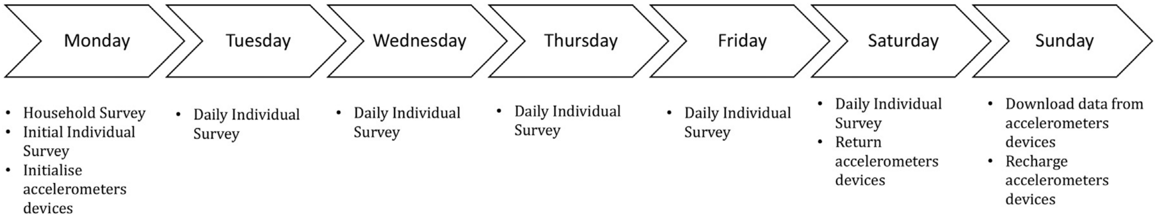

Fig. 1. Workflow of the weekly data collection.

then surveyed the individuals daily for the next five days to gather information on time use and physical activity. On Saturday, the last individual surveys were administered and accelerometry devices returned to the enumerators. On Sunday the data were downloaded and the devices recharged ready for the following round. The survey was administered with tablets and implemented using SurveyCTO (www.surveycto.com), an online platform that allows for the design, collection and monitoring of multiple surveys.

5.3. Data management

Accelerometry data were analysed and exported with Actilife, the proprietary ActiGraph software. The 30 Hz raw data were initially compressed to 3 s epochs in order to reduce the computational time without significant loss of accuracy for the activities typical of the population in the sample (Chen and Bassett, 2005). Each file was processed to detect period of "non wear" to be excluded from the analysis using Choi algorithm (Choi et al., 2011) and then the data were exported to an MS Excel dataset aggregated to one hour-intervals that included the computation of the metabolic rate, energy expenditure, and cut points to classify physical activity (into light, moderate, vigorous and very vigorous activity) based on Sasaki et al. (2011). Subsequently, for each individual we computed the Basal Metabolic rate based on the Harris–Benedict equation (Harris and Benedict, 1918).

Activities recorded in the time use questionnaire and consumption data required additional manipulations. The time use questionnaire recorded data at 1-h intervals and for each slot primary, secondary and tertiary activities (if any) were recorded. Activities were not chosen from a pre-compiled list but rather left free. Leaving the description of the activity to the enumerators increased the time spent by enumerators to fill the questionnaires but captured more granular details of the activities. The full sample included 353 activities which were later coded in 5 macro-activities and 14 micro-activities based on previously used categories that fitted within the local context (Antonopoulos and Hirway, 2009). The list of revised activities with descriptions is reported in Table 2. Individual food intakes were recorded following Gibson and Ferguson (2008). Each day, enumerators recorded the food intakes for each meal time (breakfast, mid-morning, noon, mid-afternoon, evening, before bed) while administering the individual questionnaires. Portion sizes were captured as follows: the container in which the meal was consumed was filled with water to a level equal to the volume of food consumed and weighed and net weight of the food consumed was recorded. The description of different food items/dishes consumed was standardised and recipes of the dishes consumed compiled by two enumerators. The weight of the cooked dish consumed was then converted into energy (calories) and main nutrients using conversion tables for the main ingredients.

The survey data collection produced three datasets that needed to be matched and aggregated using a unique identifier that captured the household ID, individual ID, and the day ID. For each individual the daily accelerometry data were first aggregated at hourly intervals and then merged with the recall based activity and time-use data which were also recorded at hourly intervals. The combined dataset was then merged data on individual on household characteristics. The dataset was further compressed at the day level and then at the individual level for the purpose of analysis. Data management and analysis were performed with Stata 13 (StataCorp, 2013).

Table 2
Time use activities.

Macro-activities	Micro-activities
Domestic	Child and adult care
	Household chores (cooking, cleaning, fetching water or firewood)
Economic	Crop (activities on the field, e.g. seeding, ploughing, harvesting)
	Processing (Cracking groundnuts, boiling shea nuts)
	Livestock (taking care of animals)
	Marketing (sales of products)
Social	Religious activities (funerals, naming ceremony, praying, church service)
	Social Community (chatting with friends, community assembly)
	Survey (responding to the study's questionnaire)
Resting and sleeping	Resting
	Sleeping
Personal	Eating
	Personal (bathing, hair-care)
	Leisure (playing music instruments, watching TV, reading)

6. Lessons learnt employing accelerometers devices in Ghana

6.1. Logistics, data collection, and ethical issues

The use of accelerometry devices together with the administration of daily questionnaires required careful training and motivation of enumerators to elicit the engagement and cooperation of respondents through the entire duration over which they were wearing the devices and were being administered the questionnaires.

In this particular research, communities were selected at least 3 weeks prior to the commencement of data collection. These communities were then visited to make initial contacts and also to build rapport with community leaders which included a detailed explanation of the research. The contact persons were then advised to do a listing of households in the community (where there was none in place). During a second visit, which took place between a week to three days prior to the survey, the list was used to draw a random sample of households to participate in the survey. Community leaders (mainly chiefs and/or assembly persons) then accompanied enumerators to individual participants and then introduced the enumerators to them. Using enumerators from the community (or at a minimum those who were very fluent in the local language of the area) helped in building trust which was crucial for the participants' willingness to cooperate. In general, participants were magnanimous in extending their cooperation and time for the research. Indeed, all selected individuals agreed and participated in the research; only one person, who community leaders felt strongly would not cooperate, was replaced. It is thus not surprising that just 6% of the data (hourly intervals) had to be omitted as a result of individuals not wearing the device for more than 2 h on a given day (Table 3).

Table 3
Wear-time validation: Number of missing hours/day.

Missing hours	Days	Percent
0	182	91.0
1	3	1.5
2	3	1.5
3	2	1.0
4	1	0.5
6	2	1.0
7	2	1.0
9	2	1.0
11	2	1.0
13	1	0.5
TOTAL	200	100.0

Needless to state that respect for participants and their practices and sensitivity to their concerns was pivotal to securing their cooperation. For example, occasionally respondents would mention other people, outside the acceptable definition of a household, as members of their household. Enumerators in these instances were very diplomatic and tactful in explaining to participants why those individuals could not be considered part of the said household. Enumerators were not dismissive of their views in such cases as that could jeopardise the research. Participants were also assured that the device was neither a voice nor video recorder, but only monitored their activity level without the ability to identify specific activity participants were engaged in. The need to administer the activity questionnaire separately was also explained on this basis. This assurance also minimised the risk of participants changing their activity pattern because of wearing the accelerometry devices.

Enumerators agreed with participants to visit as early as between 5:00 a.m. and 5:30 a.m. to administer the daily activity questionnaires. The choice of this time served a number of purposes, including the fact that it ensured their daily activities were not seriously interfered with; that time also tended to serve as a good reminder to those who would have otherwise forgotten to wear the device for the day; and also ideal for recalling activities undertaken the previous day before starting new ones.

There is generally respondent fatigue in rural areas in developing countries (Pettersson et al., 2005), as such incentivising research participants is becoming very popular. This becomes more important where recruited participants are to be surveyed for several days in a row. Whilst we tried not to use incentives to influence the responses of the participants, we were also careful not to let them lose interest, especially as the survey involved them wearing an accelerometry device for the entire duration of 5 days. As such, no mention was made of incentives as part of participants' briefing. However, participants were given a portion of the incentive in-kind two days into the survey to sustain their interest in continuing with the exercise. The rest of the incentive was then given to them (in cash) on the final day after interviewing them to thank them for agreeing and actually participating in the survey.

Table 4
Descriptive statistics of households.

Characteristics	Mean	SD
Age of the head of the household (years)	46.84	(10.80)
Literacy of the head (whether literate)	0.47	(0.12)
Household size	11.11	(4.77)
Number of adult males in the household	3.32	(1.73)
Number of adult females in the household	3.63	(2.17)
Number of children in the household	4.16	(2.17)
Total land holding (Acres)	6.03	(3.16)
Distance from the nearest all weather/tarmac road (Kms)	0.70	(0.67)
Distance from the nearest local trading centre (Kms)	1.02	(0.98)
Km from the nearest major products market(Kms)	5.56	(2.10)
Number of households	19	

6.2. Participants' thoughts about the use of accelerometer devices

Generally, respondents had very little knowledge of the working of the device(s) and tended to rely on the information given to them by the enumerators during the interviews. That notwithstanding they have a number of thoughts on the use of the devices. First, some respondents initially thought the devices could have some adverse effects on them but had their fears allayed by the assurances given by the enumerators. Second, some participants were concerned they were unable to see exactly what was recorded and only had to trust what they were told by the enumerators. Third, a few participants thought the devices were like some medical aid that could help them to work more on the farm. For example, a respondent on wearing the device for the first day worked so much on the farm so that he thought it was due to the device, but later noticed it was just his perception.

Indeed, respondents also held the view that even though intrusive, it felt very important to be visited by researchers on daily basis continuously for over a week for the purpose of data collection. According to them, the routine data collection also helped them take note of their daily activities and consumption. On the basis of the information given by enumerators before data collection, participants held that information generated through the research would ultimately contribute to policy on energy consumption and thus improved welfare in northern Ghana. Even though intensive, they said the data collection process was flexible enough (especially that it took place very early in the morning) to allow them go about their daily activities without much disruptions.

6.3. Practicals findings to inform scale-up studies

Critical lessons learnt on the field can serve to guide in scaling up studies deploying accelerometry devices in rural contexts in low-income countries. First, enumerators should be properly trained both in deploying the accelerometry device and also in the use of computer-assisted personal interviewing (CAPI) technology. Enumerators for this research were trained for a minimum of three days prior to the field work. Computer literacy for enumerators is, therefore, a fundamental requirement. The fact that enumerators communicated with participants directly in their local dialect also helped in securing the cooperation of participants. Another enumerator characteristic to look out for, as in all other kinds of survey, is commitment/dedication. Waking up very early in the morning to be able to reach the communities to interview participants before they start their day's activities calls for total commitment on the part of enumerators, and fortunately, we had very committed individuals as enumerators for this study. A strict workflow, including checklists, drastically mitigates the risk of losing electronic data. Enumerators were instructed to upload questionnaires from the tablet to the encrypted server every couple of days, data from accelerometry devices were uploaded weekly. These practices not only helped to preserve the integrity of the data but allowed close monitoring of activities in the field. Recharging tablets and accelerometry devices at the end of each week was double checked by the enumerators.

The enumerators faced a few challenges that should inform actions to address them. First, the participants were mildly suspicious not knowing the exact motives of enumerators on the first day of the survey despite the assurances given to them. As a result, participants generally were overly cautious on day 1, but things eased with time. Further, participants had never participated in a study as intrusive as the current one requiring them to wear a device around their waist as long as the survey lasted. It was thus natural that they initially had some reservations.

Table 5
Descriptive statistics of anthropometric and activity data of individual respondents.

	Males (n = 20)		Females (n = 20)			Full sample (n = 40)	
	Mean	SD	Mean	SD	Difference	Mean	SD
Age	45.60	(11.89)	40.75	(10.44)	4.85	43.17	(11.31)
Height (in cm)	168.43	(6.31)	159.82	(6.18)	8.60***	164.13	(7.55)
Weight (in kg)	60.28	(6.76)	55.79	(7.64)	4.49	58.03	(7.48)
BMI (Kg/m^2)	21.28	(2.41)	21.78	(2.24)	−0.50	21.53	(2.31)
TEE (kcal/d)	2480.74	(470.78)	2259.69	(367.27)	221.10	2370.21	(431.53)
AEE (kcal/d)	1048.29	(397.29)	1067.63	(299.07)	−19.35	1057.96	(347.22)
BMR	1432.46	(101.57)	1192.06	(100.61)	240.40***	1312.26	(157.40)
PAL	1.72	(0.24)	1.89	(0.21)	−0.17*	1.81	(0.24)
Light activity (%)	0.86	(0.04)	0.84	(0.03)	0.02	0.85	(0.04)
Moderate activity (%)	0.12	(0.03)	0.14	(0.03)	−0.02*	0.13	(0.03)
Vigorous activity (%)	0.01	(0.01)	0.01	(0.01)	0.00	0.01	(0.01)
Very Vigorous activity (%)	0.00	(0.00)	0.00	(0.00)	−0.00	0.00	(0.00)
Steps / day	11,735.25	(3036.43)	16,488.88	(3544.41)	−4753.6***	14,112.06	(4050.46)
Days	4.80	(0.75)	4.60	(0.82)	0.20	4.70	(0.69)
Hours (over 120)	119.60	(0.75)	119.95	(0.22)	−0.35	119.78	(0.58)

Asterisks show level of significance ***= significant at 0.1% level, **=significant at 1% level and *=significant at 5% level.

7. Results

7.1. Field site and descriptive statistics of households and respondents

Data on physical activity and time use were collected from a sample of 20 men and 20 women in 19 households from eight different communities in Wa Municipality in Upper West region in northern Ghana. The region is located in the guinea savannah vegetation belt dominated by grassland with scattered draught resistant trees. The economy of the district is agrarian with about 80% of the population engaged in agriculture. The major crops grown in the area are maize, sorghum, millet, groundnut and cowpea. Goat, sheep, pigs and poultry are the main livestock in the area. The area is characterised by one rainy season, from May to September. Conditional to regular rainfalls, land preparation tends to start mid-May, immediately followed by sowing and seeding. Harvest time is expected in September. During the time of the survey, we mainly captured the sowing/seeding phase (ploughing and transplanting) and land maintenance (weeding). Depending on the crops grown, some households had started harvest at the end of the survey. This is an important consideration in discussing and contextualising the results, since energy expenditure and time use profiles are likely to be influenced by seasonality factors and the timing of the data collection exercise.

The descriptive statistics of the selected households are summarised in Table 4. The households selected for the survey were rural households with agriculture as their principal economic activity and main source of livelihood and income. All households were headed by males. Less than half of the household heads were literate. Household sizes in this part of Ghana tend to be large with an average size of 11.11 members and includes all individuals living within a household compound. Indeed, the household size recorded for the survey communities is almost twice of the 6.4 persons recorded for rural Wa Municipality in the most recent census (GSS, 2014a). All households had access to agricultural land with an average holding of 6.03 acres spread over an average of 2 plots. In terms of access to infrastructure, the households were fairly close to all weather roads but were still at a considerable distance from the nearest agricultural product market. According to Ghana Statistical Service (2014b), the incidence of poverty in the Upper West region of Ghana where the selected communities are located is the highest – 70.7%.

Fig. 2. Distribution of BMI of male and female respondents.

Table 5 presents the descriptive statistics, anthropometric and activity data for the male and female respondents who wore the accelerometry devices in the selected households for a period of 5 days and answered the daily activity and time-use questionnaires.

In Table 5, the differences between male and female respondents are of interest, although owing to the small sample size, many of the differences are not statistically significant. Men are significantly taller than women and their average weight is also higher than that of women by 5 Kgs, although the difference in weight between men and women is not significant. While women have a higher mean BMI than men, there is no statistically significant difference between the BMI of men and women. The distribution of BMI of men and women in the sample may be seen in Fig. 2. The modal BMI for women is clearly greater than that for men. Only four respondents (2 males and 2 females) have a BMI of less than 18.5, while four respondents (2 males and 2 females) have a BMI in excess of 25 (which is the threshold for being overweight). This suggests that the incidence of calorie undernutrition is quite limited – as chronic calorie deficits would tend to be reflected in BMI values below 18.5.

The Basal Metabolic Rate (BMR) is derived from standard equations[2] that relate resting energy expenditure to age, gender, height and weight and are expectedly lower for women compared to men. However, the Activity Energy Expenditure (AEE) which reflects energy expenditure for physical activity is higher for women than for men. This gives women a higher Physical Activity Level (PAL) (Total Energy Expenditure/BMR) than for men and the difference in PAL is significant. While the Total Energy Expenditure (TEE) for men is greater than that for women, women are in fact more physically active than men. Fig. 3 shows the distribution of PAL for men and women,

[2] The BMR for men and women has been calculated using the Harris-Benedict equation (Harris and Benedict, 1918).

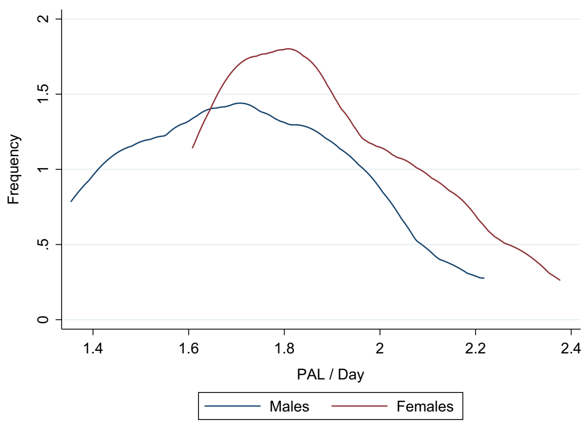

Fig. 3. Distribution of PAL by gender.

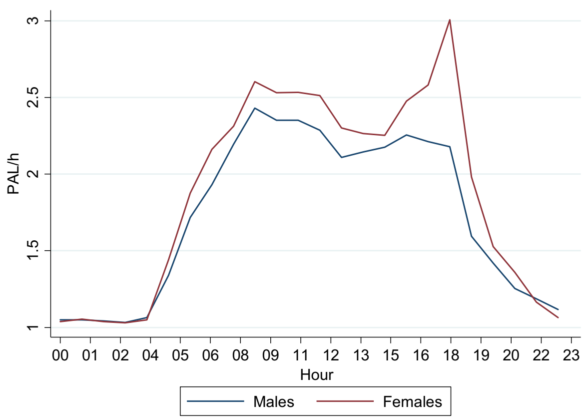

Fig. 4. Mean PAL for men and women through the day.

with the distribution for women lying to the right of the distribution for men. Fig. 4 shows how the mean PAL for men and women varies through the course of the day. The PAL for women follows that for men fairly closely from the start of the day to late afternoon (around 4 P.M.), but thereafter, there is a sharp spike in the PAL for women which is not matched by men. This probably reflects the greater involvement of women in cooking, child care and other domestic chores in the evening while men tend to wind down. Women also record a significantly higher number of steps than men during the course of the day which may reflect the fact that they are on their feet for a much longer duration as they carry out domestic chores. Most of the energy expenditure for both men and women comes from light and moderate activity with the proportion of energy expenditure coming from vigorous/very vigorous activity being less than 1%.

The mean total energy expenditure for men (2480 kcal) and women (2259 kcal) appears to be considerably less than the norm of 2900 cal per adult equivalent used in Ghana (Ghana Statistical Service, 2014) for the computation of the poverty line. While the sample in our study is not representative of rural Ghana, what the results suggest is that any assessment of poverty based on a normative calorie requirement of 2900 kcal per adult equivalent per day may overstate the incidence of poverty or calorie deficits among the rural poor in Ghana.

7.2. Energy expenditure and time use

The proportion of energy expenditure and time use related to different activities for men and women is presented in Table 6.

For men, nearly three quarters of the energy expenditure comes from economic and social activities while domestic activities account for less than 5% of energy expenditure. The share of energy expenditure from economic activities is greater for men (51%) than for women (38%). However, within economic activities, women expend a larger share of energy on marketing and processing than men. This appears to reinforce the observations in the literature that in rural Ghana women play a dominant role in the marketing of agricultural produce (Boserup and Kanji, 2007). We have very little data on livestock activities in the data set to make a comparison between men and women. Expectedly, women spend a much larger share (30%) of their energy on domestic activities than men with the major portion derived from household chores. Men expend 23% of their energy on social activities while in the case of women it is only 10%. The larger involvement of women with domestic and child care activities appears to leave them less room for social interactions. Women spend 15% of their energy on personal activities which is greater than for men. However, the energy spent by women on "eating" may overlap other activities such as serving meals, feeding children.

Table 6
Energy expenditure of activities.

	Males AEE (%)	Females AEE (%)	Full sample AEE (%)
Domestic activities	0.04	0.30	0.17
Child / adult care	0.00	0.02	0.01
Household chores	0.05	0.28	0.16
Economic activities	0.51	0.38	0.44
Crop production	0.47	0.24	0.35
Livestock	0.02	0.00	0.02
Marketing	0.03	0.08	0.05
Processing	0.00	0.03	0.01
Sleeping and resting	0.12	0.07	0.10
Resting	0.09	0.06	0.07
Sleeping	0.04	0.02	0.03
Social activities	0.23	0.10	0.16
Religious activities	0.06	0.04	0.04
Social interactions	0.13	0.05	0.09
Official (survey)	0.03	0.02	0.03
Personal activities	0.11	0.15	0.13
Eating	0.05	0.10	0.07
Leisure	0.00	0.00	0.00
Personal care	0.05	0.04	0.05

7.3. Energy intensity of activities

The Activity Energy Expenditure (AEE) and PAL associated with different activities for men and women in the sample are summarised in Table 7.

It may be seen from the table that economic activities have the highest AEEs followed by domestic activities, while social activities and personal activities have the lowest AEEs. AEEs for economic and social activities are higher for men than women, similar for domestic activities and significantly lower for men in the case of personal activities. The higher AEE for personal activities for women may arise on account of the nature of other activities that are concurrently undertaken by women when they are involved with personal activities (e.g., eating or leisure activity may be undertaken concurrently with child care). While the AEEs for women are lower than for men, it is notable that for economic, domestic, social and personal activities, women have a higher PAL than for men. The activities undertaken by men in these categories are more energy intensive, but women are physically more active in the performance of these activities (i.e., requiring greater "effort" in relation to their BMR)- contributing to the overall higher levels of PAL for women discussed earlier. Bouts of vigorous and very vigorous activity are significantly higher for men for economic activities and significantly higher for women for social activities. The AEE and PAL for selected agricultural activities are presented in Table 8. For agricultural activities that are undertaken by both men and women, a similar pattern is observed. AEEs for men are higher than for women, but women are physically more active in the

Table 7
Activity Energy Expenditure and Physical Activity Levels for different activities.

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Domestic activities							
AEE (kcal/hour)	63.12	(46.18)	63.09	(45.36)	0.03	63.09	(45.42)
PAL	2.03	(0.74)	2.26	(0.88)	−0.23*	2.23	(0.87)
Light activity (mins/hour)	46.27	(12.12)	43.81	(13.07)	2.46	44.14	(12.97)
Moderate activity (mins/hour)	9.48	(7.10)	11.80	(9.27)	−2.32	11.50	(9.04)
Vigorous activity (mins/hour)	1.40	(1.94)	1.19	(1.10)	0.21	1.22	(1.24)
Very Vigorous activity (mins/hour)	0.17	(0.28)	0.15	(0.20)	0.02	0.15	(0.21)
Observations	66		439			505	
Economic activities							
AEE (kcal/hour)	101.44	(65.83)	83.48	(59.95)	17.95***	93.07	(63.76)
PAL	2.67	(1.04)	2.69	(1.17)	−0.02	2.68	(1.10)
Light activity (mins/hour)	40.82	(11.83)	42.18	(13.33)	−1.35	41.45	(12.56)
Moderate activity (mins/hour)	15.77	(9.07)	16.14	(12.70)	−0.36	15.94	(10.91)
Vigorous activity (mins/hour)	2.18	(3.25)	1.49	(1.93)	0.69***	1.86	(2.74)
Very Vigorous activity (mins/hour)	0.28	(0.61)	0.15	(0.25)	0.14***	0.22	(0.48)
Observations	509		444			953	
Sleeping and resting							
AEE (kcal/hour)	13.53	(28.89)	8.86	(22.37)	4.67***	11.32	(26.11)
PAL	1.23	(0.48)	1.18	(0.46)	0.05*	1.21	(0.47)
Light activity (mins/hour)	39.61	(25.86)	35.88	(27.47)	3.74**	37.85	(26.69)
Moderate activity (mins/hour)	2.08	(4.43)	1.50	(4.28)	0.58**	1.80	(4.37)
Vigorous activity (mins/hour)	0.28	(0.76)	0.20	(0.50)	0.08**	0.24	(0.65)
Very Vigorous activity (mins/hour)	0.06	(0.19)	0.04	(0.11)	0.02**	0.05	(0.16)
Observations	922		829			1751	
Social activities							
AEE (kcal/hour)	41.59	(35.42)	44.76	(36.66)	−3.17	42.53	(35.80)
PAL	1.70	(0.57)	1.90	(0.71)	−0.20***	1.76	(0.62)
Light activity (mins/hour)	48.42	(12.81)	45.49	(14.75)	2.92**	47.55	(13.47)
Moderate activity (mins/hour)	7.15	(5.76)	8.30	(7.70)	−1.15*	7.49	(6.42)
Vigorous activity (mins/hour)	0.64	(1.04)	0.81	(0.78)	−0.17*	0.69	(0.97)
Very Vigorous activity (mins/hour)	0.10	(0.20)	0.14	(0.24)	−0.04*	0.11	(0.22)
Observations	533		226			759	
Individual activities							
AEE (kcal/hour)	39.14	(46.83)	54.25	(46.81)	−15.11***	46.64	(47.38)
PAL	1.65	(0.74)	2.08	(0.91)	−0.44***	1.86	(0.86)
Light activity (mins/hour)	44.88	(18.75)	45.36	(14.40)	−0.47	45.12	(16.72)
Moderate activity (mins/hour)	6.07	(6.34)	10.19	(10.40)	−4.12***	8.12	(8.83)
Vigorous activity (mins/hour)	0.80	(1.70)	1.07	(1.21)	−0.27*	0.93	(1.48)
Very Vigorous activity (mins/hour)	0.13	(0.39)	0.18	(0.33)	−0.04	0.16	(0.36)
Observations	274		270			544	

Asterisks show level of significance ***= significant at 0.1% level, **=significant at 1% level and *=significant at 5% level.

Table 8
AEE and PAL for selected agricultural activities.

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Ploughing							
AEE (kcal/hour)	146.95	(100.93)	105.38	(50.56)	41.57	142.40	(97.34)
PAL	3.31	(1.53)	3.35	(1.09)	−0.0400	3.32	(1.48)
Observations	65		8			73	
Transplanting							
AEE (kcal/hour)	110.76	(59.06)	81.82	(33.70)	28.94	104.50	(55.49)
PAL	2.87	(0.92)	2.92	(0.79)	−0.0482	2.88	(0.89)
Observations	29		8			37	
Land clearing							
AEE (kcal/hour)	121.15	(68.93)				121.15	(68.93)
PAL	2.90	(1.06)				2.90	(1.06)
Observations	26					26	
Spraying							
AEE (kcal/hour)	94.53	(46.84)				94.53	(46.84)
PAL	2.59	(0.79)				2.59	(0.79)
Observations	12					12	

Table 9
Time use by activity.

Activity	Males			Females				Full sample		
	Mean	SD	Percent	Mean	SD	Percent	Difference	Mean	SD	Percent
Domestic activities	0.67	0.66	2.79%	4.98	2.1	20.75%	−4.31***	2.83	2.67	11.79%
Child / adult care	0.01	0.04	0.04%	0.47	0.53	1.96%	−0.46***	0.24	0.44	1.00%
Household chores	0.64	0.62	2.67%	4.52	1.85	18.83%	−3.88***	2.58	2.39	10.75%
Economic activities	5.25	2.63	21.88%	4.78	2.33	19.92%	0.48	5.02	2.47	20.92%
Crop production	4.57	2.69	19.04%	3.23	2.39	13.46%	1.34	3.9	2.61	16.25%
Livestock	0.17	0.47	0.71%	0.07	0.27	0.29%	0.1	0.12	0.38	0.50%
Marketing	0.52	1.04	2.17%	1	1.27	4.17%	−0.48	0.76	1.17	3.17%
Processing	0.01	0.04	0.04%	0.48	0.68	2.00%	−0.47**	0.25	0.53	1.04%
Sleeping and resting	9.55	1.33	39.79%	8.91	1.08	37.13%	0.61	9.23	1.24	38.46%
Resting	3.49	1.15	14.54%	3.24	0.88	13.50%	0.25	3.37	1.02	14.04%
Sleeping	6.06	0.56	25.25%	5.67	0.36	23.63%	0.39*	5.87	0.5	24.46%
Social activities	5.68	3.6	23.67%	2.37	1.74	9.88%	3.31***	4.02	3.25	16.75%
Religious activities	1.64	1.55	6.83%	0.86	1	3.58%	0.78	1.25	1.35	5.21%
Social interactions	3.22	3	13.42%	1.1	1.31	4.58%	2.13**	2.16	2.53	9.00%
Official (survey)	0.82	0.39	3.42%	0.41	0.25	1.71%	0.41***	0.61	0.38	2.54%
Personal activities	2.84	0.81	11.83%	2.96	0.59	12.33%	−0.12	2.9	0.7	12.08%
Eating	1.3	0.55	5.42%	1.77	0.48	7.38%	−0.47**	1.54	0.56	6.42%
Leisure	0.24	0.5	1.00%	0.15	0.29	0.63%	0.08	0.19	0.4	0.79%
Personal care	1.3	0.61	5.42%	1.03	0.39	4.29%	0.27	1.17	0.52	4.88%

Asterisks show level of significance ***= significant at 0.1% level, **=significant at 1% level and *=significant at 5% level.

performance of these activities.

The AEE and PAL patterns for men and women in the sample for sub-categories of domestic, economic, social and personal activities are presented in Appendix B. The AEE for agricultural activities from our data are considerably less than the AEE estimates from the literature (Table 5). In most of the studies in the literature, AEE per hour has been estimated by taking the energy expended on an activity for a unit interval (e.g., a minute) and assuming that energy expenditure is maintained at that level for a period of one hour. This method does not allow for intervals of inactivity or rest during activities such as ploughing or weeding and, therefore, tends to overestimate the energy expenditure associated with different agricultural activities. The data from accelerometry devices gives a more reliable estimate of energy expenditure for agricultural activities because it allows for varying levels of physical exertion during an hour of a specific agricultural activity.

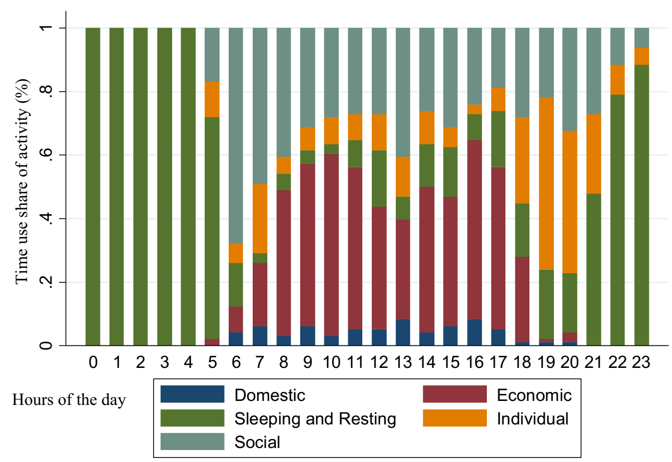

Fig. 5. Time use pattern through the day – men.

7.4. Time use patterns

The average time use patterns of men and women in the sample over a period of 5 days when they were wearing the accelerometry devices is summarised in Table 9.

For the sample as a whole, economic activities account for 21% of time use. Sleep and rest account for 38% while personal care, domestic and social activities account for 41% of time use. Both men and women devote nearly 5 h a day to economic activities and there is no significant difference between men and women. Men spend a larger proportion of time on crop production activities while women spend a larger proportion on marketing and processing activities. There are significant differences between men and women in domestic activities with women spending an average of 5 h a day on domestic activities as against just 0.67 h by men. The difference is mainly on account of the time spent by women on household chores. The time spent by women on child care appears to be low at 2% - however, that may be reflecting the fact that child care may be undertaken concurrently with other activities (see discussion below on the prevalence of multi-tasking along with different primary activities). Men spend an average of 5.68 h (23.67%) on social activities while women spend only an average of 2.37 h (9.88%). What this suggests is that the extra burden of household chores on women reduces the time available for social interactions, but does not affect their involvement in economic activities.

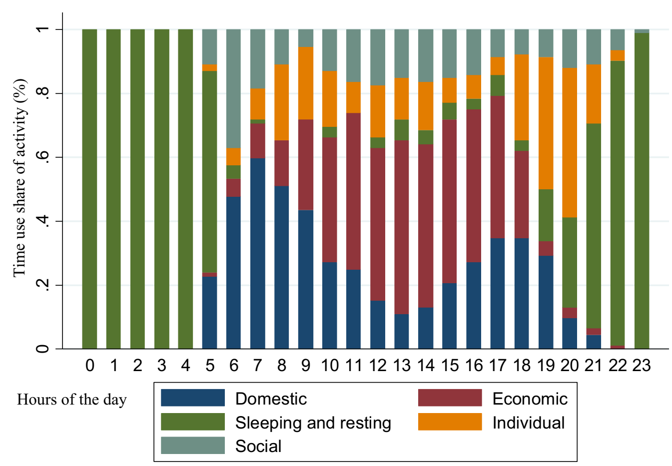

Fig. 6. Time use pattern through the day – women.

There are no significant differences between men and women in time spent on personal care, except for “eating” where women appear to spend more time. As noted previously, “eating” time for women may include other complementary activities like serving meals, feeding

Table 10
Energy expenditure and time use for activities.

	Males		Females		Full sample	
	AEE (%)	Time (%)	AEE (%)	Time (%)	AEE (%)	Time (%)
Domestic activities	0.04	0.03	0.30	0.21	0.17	0.12
Child / adult care	0.00	0.00	0.02	0.02	0.01	0.01
Household chores	0.05	0.03	0.28	0.19	0.16	0.11
Economic activities	0.51	0.22	0.38	0.20	0.44	0.21
Crop production	0.47	0.19	0.24	0.13	0.35	0.16
Livestock	0.02	0.01	0.00	0.00	0.02	0.01
Marketing	0.03	0.02	0.08	0.04	0.05	0.03
Processing	0.00	0.00	0.03	0.02	0.01	0.01
Sleeping and resting	0.12	0.40	0.07	0.37	0.10	0.38
Resting	0.09	0.15	0.06	0.14	0.07	0.14
Sleeping	0.04	0.25	0.02	0.24	0.03	0.24
Social activities	0.23	0.24	0.10	0.10	0.16	0.17
Religious activities	0.06	0.07	0.04	0.04	0.04	0.05
Social interactions	0.13	0.13	0.05	0.05	0.09	0.09
Official (survey)	0.03	0.03	0.02	0.02	0.03	0.03
Individual activities	0.11	0.12	0.15	0.12	0.13	0.12
Eating	0.05	0.05	0.10	0.07	0.07	0.06
Leisure	0.00	0.01	0.00	0.01	0.00	0.01
Personal care	0.05	0.05	0.04	0.04	0.05	0.05

children etc. which may extend the duration over which they have their meals.

The average time use patterns through the day (by the hour) for men and women are presented in Figs. 5 and 6 respectively.

The graphs in Figs. 5 and 6 show clear differences in the activity patterns of men and women through the day. While the total contribution (in terms of hours) to economic activities is the same for men and women, the contribution of women to economic activities comes later in the day. The proportion of time devoted by women to domestic activities during the course of the day is quite striking. Women's domestic activities are spread through the day into the evening and they get very little rest during the day. The much higher proportion of time spent by men on social activities during day time is also notable feature in the graphs. Personal activities for women are spread through the day while for men it tends to be concentrated earlier in the day and in the evening hours.

7.5. Energy expenditure and time use

A comparison of the proportion of energy expenditure and time-use for different activities (Table 10) provides a number of interesting insights. For economic activities, while men and women spend a similar proportion of time (20–22%), the share of energy expenditure for men on economic activities is greater (51% versus 38% for women).

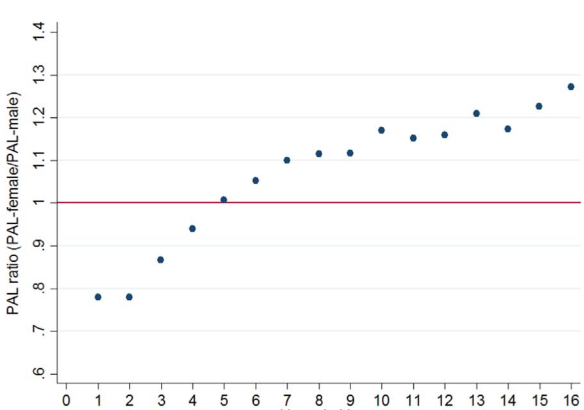

Fig. 7. Intra-household PAL ratios between husbands and wives.

Men spend a greater proportion of time on crop production activities. These figures suggest that men probably undertake the more physically demanding (energy intensive) crop production activities. Women spend a greater proportion of their time on marketing and processing activities but these are not as energy intensive as other crop production activities. While men and women spend a similar amount of energy on domestic activities, the time-share of women (21%) for domestic activities is much larger than it is for men (4%). The large proportion of time spent by women in domestic activities appears to leave them much less time for social activities and interactions. The time spent on sleeping and resting and for personal care activities are broadly similar for men and women.

7.6. Intra-household gender differences in energy expenditure and time use

The data collected in this study also allows a preliminary exploration of intra-household gender differences in energy expenditure and time-use in northern Ghana. We examined these differences using data from husband-wife pairs from 16 households. While the sample size was too small for a systematic examination of the determinants of these differences, the data, nevertheless suggest certain distinct patterns in gender differences in energy expenditure and time use within agricultural households.

The total daily energy expenditure of males and females in a household depends on their BMR and AEE. As the BMR can vary between individuals depending on the height, weight, age, and gender, differences in total energy expenditure between males and females may not reflect differences in physical activity. We, therefore, use the ratio of PAL (PAL_{female}/PAL_{male}) of spouses within the same household to assess gender differences in physical activity levels. A PAL ratio greater than one would show that females have higher physical activity levels than males. Fig. 7 shows the female to male PAL ratio for the 16 households (husband-wife pairs) in the sample.

Except in four households, wives had a higher level of PAL than their husbands. On average, wives had a PAL that was 7% higher than that of their husbands. These figures suggest that not only are women physically more active than men on average as a group (See Fig. 2), but within households, wives are more physically active in relation to their husbands.

Fig. 8a–d explore how the PAL ratio in households varies with the

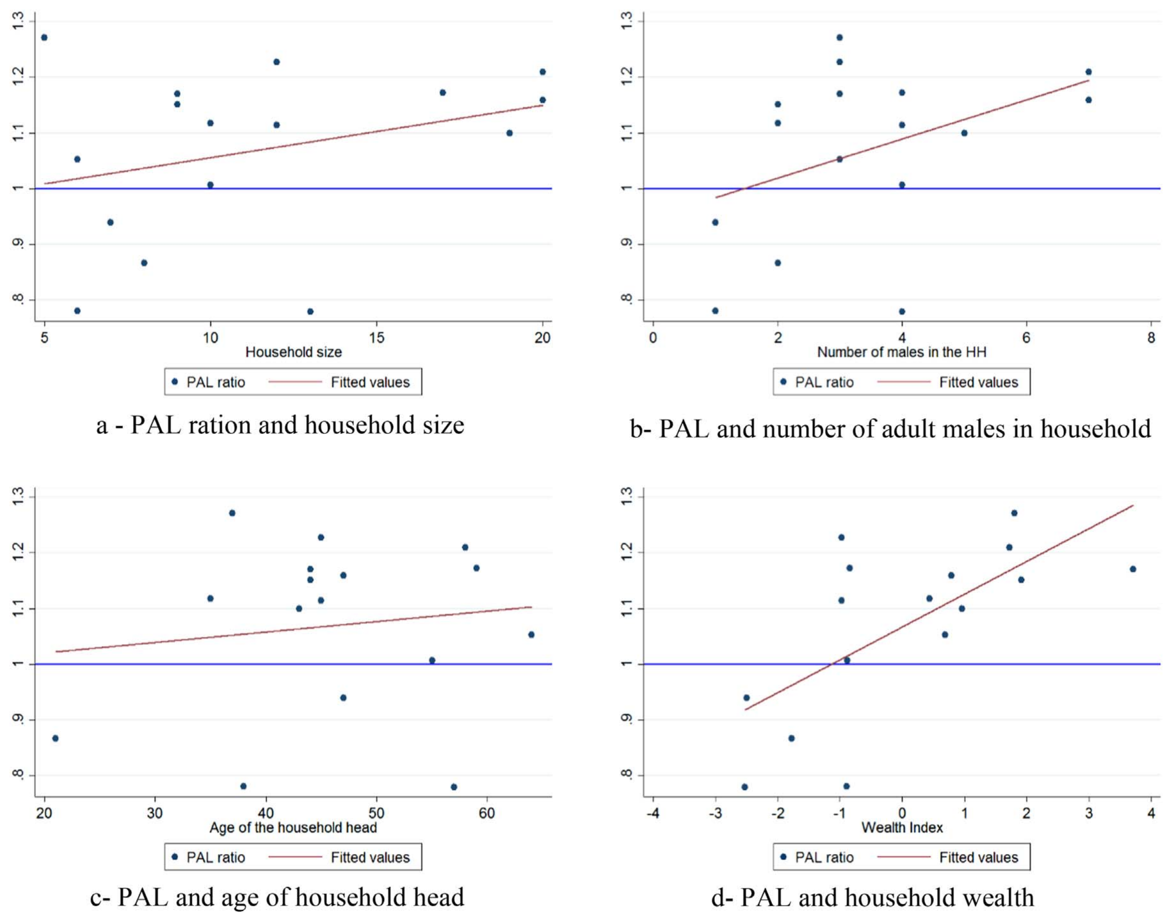

Fig. 8. a–d Correlations of PAL ratio and household's characteristics.

Table 11
Intra-household gender differences in energy expenditure and time-use.

Activities	AEE			Time use		
	Husbands (A)	Wives (B)	Difference (B-A) (% points)	Husbands (A)	Wives (B)	Difference (B-A) (% points)
Domestic	4%	29%	−25%	3%	21%	−18%
Economic	51%	39%	12%	22%	18%	4%
Sleeping and Resting	12%	7%	5%	40%	37%	23%
Individual (Personal)	11%	15%	−4%	12%	13%	−1%
Social	23%	10%	13%	23%	10%	13%

size of the household, number of adult males in the household, the age of the household head and the wealth[3] of the household. The gender differences in PAL appear to increase with household size and the number of adult males in the household. It also appears to increase with the age of the household head and the wealth of the household. Higher PAL ratios associated with household size and number of adult males may arise from the increased burden of domestic chores for females in larger households. Higher PAL associated with increasing age of the (male) household head may reflect the changing nature of economic and non-economic activities performed by the household heads as they age. It is interesting that gender differences in PAL do not reduce with increasing household wealth. Higher PAL ratios in wealthier households may reflect the changing nature of occupations undertaken by males as a household becomes wealthier while female activities and time use patterns may change little. For instance, a wealthier farm household with access to mechanisation may require less strenuous physical activity on farms by male working members. These relationships need to be explored further with larger data sets.

The patterns of AEE and time-use by husbands and wives within households are compared in Table 11. The observed differences largely conform to the pattern of differences between males and females considered as groups (Table 10). The largest differences in time use between husbands and wives are found in domestic work and social activities – with wives spending a much larger proportion of their time on domestic activities and husbands spending a much larger proportion of their time on social activities. Wives spend less time sleeping and resting but spend more time on personal care. There is not a large difference in the in the time spent in economic activities between husbands and wives in agricultural households. However, husbands spend a much larger proportion of their AEE on economic activities than wives, which may reflect differences in the nature (energy intensity) of economic activities undertaken. The difference in AEE

[3] The wealth index is a composite measure based on the household's ownership of assets and materials used for housing construction and is designed to capture the household's cumulative living standard (Rutstein and Kiersten, 2004). It is constructed computing the first vector of a principal component analysis that includes the relevant household's assets and housing materials.

for domestic activities between husbands and wives is larger than what would be suggested by the differences in time use. For social activities the differences in AEE are broadly proportional to the differences in time use.

7.7. Discussion

Combining energy expenditure data from accelerometry devices with time-use data provides a window into rural agricultural and livelihood activities which had hitherto not been available. The methods adopted allow a precise and robust delineation of intra-household labour allocation and its implications for the nutritional requirements of men and women. Although the results confirm the stylised facts relating to energy expenditure of men and women in rural households (e.g., that energy expenditure for men is greater than women, men undertake the more physically demanding (energy intensive) agricultural production tasks), they also provide additional insights into the physical exertion and time demands that rural agricultural and livelihood activities make on men and women. The finding that women are required to maintain a higher PAL through the day in relation to men is particularly important because it suggests that there may be constraints to labour intensification for women through the adoption of new technologies or involvement in additional economic activities. The results from this small sample cannot be generalised to the entire rural population, but there appears to be a strong indication that the energy expenditure levels of men and women in rural areas in Ghana is considerably less than the normative energy requirements assumed for the calculation of poverty lines and incidence. The use of normative energy requirements based on age and gender may overstate the incidence and depth of calorie deficits and hunger. This proposition is supported within this small sample by the BMI distribution of the respondents, but needs to be examined with larger data sets that are representative of the rural population. PAL in rural agricultural and livelihood activities are much higher than in sedentary urban living, but these activities predominantly involve light and moderate levels of activity – rather than vigorous and very vigorous levels of activity commonly associated with the notion of 'hard rural life'.

It is somewhat surprising to find that men and women in rural Ghana are able to devote only 5 h a day to economically productive activities. Income enhancing interventions may need to be aimed at increasing the window available for engaging in economic activities. However, for women this may involve sharp trade-offs with time spent on household activities (which includes child care and nutrition). Interventions may, therefore, need to be designed to mitigate these trade-offs, which may call for an examination of the time and energy expenditure demands imposed by lack of transport, public health, drinking water and sanitation infrastructure (e.g., women may need to walk far to fetch water or firewood or access markets or public health facilities). Interventions that reduce the time and energy expenditure demands from these domestic activities may mitigate the trade-offs and improve calorie adequacy status even at existing levels of intake. The detailed examination of energy expenditure and time use patterns can facilitate the development of approaches to nutrition and welfare enhancement that are not focused on productivity/yield improving innovations alone.

8. Conclusion

In this study we reported the experience of using accelerometry devices in Ghana. Scaled-up empirical application of the methods developed can facilitate a clearer delineation of the agriculture-nutrition impact pathways. Specifically, the methods can contribute to:

i. More accurate assessments of the incidence, depth and severity of undernutrition and poverty (in cases where undernutrition levels are defined in relation to average reference calorie requirements as is the case in the assessments of global hunger and food insecurity made by the FAO and IFPRI (FAO et al., 2015; von Grebmer et al., 2014) in low and middle-income countries). Although recent initiatives and studies have highlighted the need for better data to monitor food systems and nutrition outcomes (Global Panel, 2015; IFPRI, 2015; Masters et al., 2014), the assessment of the incidence of undernutrition/poverty is still often based on expenditure/consumption/dietary surveys using normative energy requirement figures (which may vary by age group or gender). Knowledge of energy expenditure profiles will provide a better understanding of the influence of livelihood strategies and activities, environmental factors (e.g., climate and temperature) and access to health and physical infrastructure on energy expenditure patterns and inform better targeting of nutrition interventions.

ii. Modelling energy expenditure data within an efficiency framework can contribute to the development of the notion "energy use efficiency" in rural livelihoods and its determinants. The protocols and methods can be used to understand the short-term and long-term effects of ill-health and disease on agricultural productivity and wage earnings. More generally, we envisage several applications of the methods in labour economics where effort is usually not observed or is empirically not measurable.

iii. A better understanding of intra-household labour and physical activity allocation decisions, including those associated with the adoption of productivity-enhancing agricultural innovations. In particular, the methodology will be used to better understand the labour intensification for women associated with the adoption of improved agricultural technologies and the gender differentiation in the labour allocation decisions of rural households (Ellis, 1998; Udry, 1996). Such approach should cover as much as possible the whole agricultural season, since intra-allocation of labour can significantly vary across the various agricultural activities (Kashiwazaki et al., 2009). The results of the study will provide insights into how intra-household labour allocation decisions may influence the energy expenditure profile of undernourished members of rural households. Gender or age-differentiated household labour allocation decisions may influence the willingness of households to adopt new agricultural technologies or practices. Insights will also be gained into the trade-offs between different livelihood activities – for instance, the intensification of women's labour in agriculture may involve reduced maternal time for childcare.

iv. A better understanding of the link between productivity-enhancing interventions and nutrition outcomes for individuals within a household. The linkage between agricultural development and nutrition outcomes in developing countries is the focus of a number of research programmes, as there appears to be a disconnect between gains in agricultural productivity and improvement in nutrition outcomes (e.g. Leveraging Agriculture for Nutrition in South Asia (LANSA) and Tackling the Agriculture and Nutrition Disconnect in India). Empirical measurement of energy expenditure profiles will help in clearer delineation of the pathways of impact from agricultural growth to nutrition outcomes.

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Appendix A

See Fig. A1.

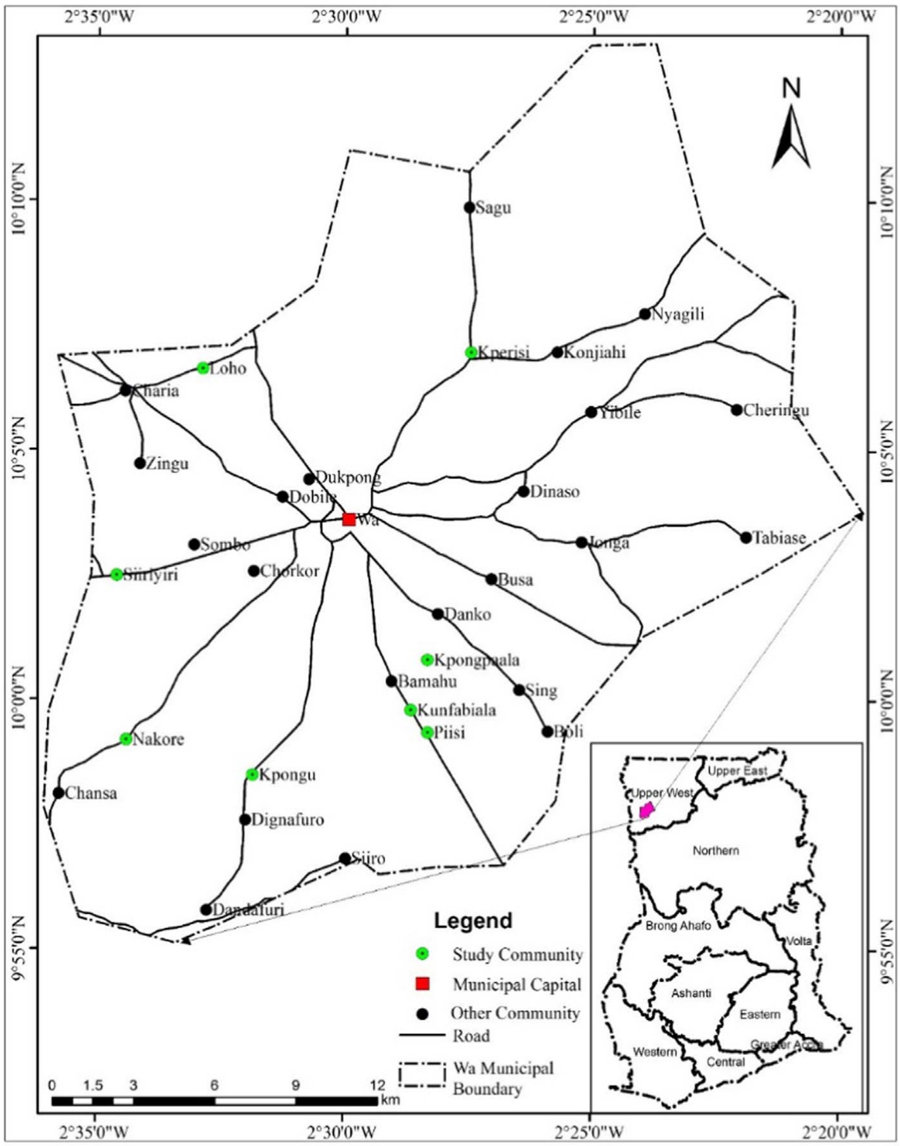

Fig. A1. Map of Wa Municipal, Ghana showing study communities.

Appendix B. Individual descriptive statistics for time use (micro activities data / hour)

Domestic Activities

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Child and adult care							
AEE (kcal/hour)	0.05	(.)	46.31	(35.18)	−46.260	45.18	(35.48)
PAL	1.00	(.)	1.93	(0.67)	−0.932	1.91	(0.68)
Light activity (mins/hour)	10.00	(.)	47.98	(10.84)	−37.980	47.05	(12.24)
Moderate activity (mins/hour)	0.00	(.)	8.96	(6.83)	−8.964	8.75	(6.88)

Vigorous activity (mins/hour)	0.00	(.)	0.91	(0.77)	−0.908	0.89	(0.77)
Very Vigorous activity (mins/hour)	0.00	(.)	0.10	(0.14)	−0.100	0.10	(0.14)
Observations	1		40			41	
Household chores (cooking, cleaning, fetching water or firewood)							
AEE (kcal/hour)	65.67	(45.66)	64.77	(45.95)	0.894	64.89	(45.86)
PAL	2.07	(0.73)	2.29	(0.89)	−0.217	2.26	(0.87)
Light activity (mins/hour)	46.49	(11.35)	43.40	(13.21)	3.097	43.82	(13.01)
Moderate activity (mins/hour)	9.85	(7.04)	12.09	(9.44)	−2.238	11.78	(9.17)
Vigorous activity (mins/hour)	1.46	(1.96)	1.22	(1.12)	0.240	1.26	(1.27)
Very Vigorous activity (mins/hour)	0.17	(0.28)	0.15	(0.20)	0.023	0.15	(0.21)
Observations	63		399			462	

Economic Activities

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Crop (activities on the field, e.g. seeding, ploughing, harvesting)							
AEE (kcal/hour)	106.91	(66.59)	82.38	(54.93)	24.53***	96.97	(63.25)
PAL	2.76	(1.05)	2.70	(1.13)	0.053	2.73	(1.08)
Light activity (mins/hour)	39.74	(11.86)	41.88	(13.12)	−2.143*	40.60	(12.42)
Moderate activity (mins/hour)	16.57	(8.97)	16.45	(12.57)	0.124	16.52	(10.57)
Vigorous activity (mins/hour)	2.31	(3.40)	1.45	(1.81)	0.859***	1.96	(2.89)
Very Vigorous activity (mins/hour)	0.29	(0.63)	0.15	(0.25)	0.146***	0.23	(0.51)
Observations	442		301			743	
Processing (Cracking groundnuts, boiling shea nuts)							
AEE (kcal/hour)	128.58	(.)	77.38	(46.88)	51.21	78.42	(46.96)
PAL	3.29	(.)	2.54	(0.95)	0.756	2.55	(0.95)
Light activity (mins/hour)	35.30	(.)	44.22	(10.26)	−8.924	44.04	(10.23)
Moderate activity (mins/hour)	22.25	(.)	13.92	(9.57)	8.332	14.09	(9.54)
Vigorous activity (mins/hour)	2.30	(.)	1.71	(1.94)	0.587	1.72	(1.92)
Very Vigorous activity (mins/hour)	0.15	(.)	0.15	(0.22)	0.00417	0.15	(0.22)
Observations	1		48			49	
Livestock (taking care of animals)							
AEE (kcal/hour)	75.59	(48.15)	68.42	(33.40)	7.169	73.50	(43.76)
PAL	2.32	(0.84)	2.57	(0.80)	−0.242	2.39	(0.82)
Light activity (mins/hour)	45.42	(9.17)	42.81	(10.87)	2.613	44.66	(9.53)
Moderate activity (mins/hour)	12.66	(7.90)	15.93	(10.26)	−3.264	13.62	(8.56)
Vigorous activity (mins/hour)	1.72	(1.68)	1.21	(0.78)	0.516	1.57	(1.48)
Very Vigorous activity (mins/hour)	0.19	(0.28)	0.06	(0.08)	0.134	0.15	(0.24)
Observations	17		7			24	
Marketing (sales of products)							
AEE (kcal/hour)	58.66	(45.96)	91.80	(80.76)	−33.14**	79.64	(71.65)
PAL	1.99	(0.74)	2.72	(1.45)	−0.738***	2.45	(1.28)
Light activity (mins/hour)	49.48	(8.46)	42.03	(15.58)	7.450**	44.76	(13.85)
Moderate activity (mins/hour)	9.23	(7.71)	16.30	(14.73)	−7.074**	13.71	(13.04)
Vigorous activity (mins/hour)	1.09	(1.84)	1.52	(2.34)	−0.430	1.36	(2.18)
Very Vigorous activity (mins/hour)	0.20	(0.48)	0.15	(0.28)	0.0537	0.17	(0.36)
Observations	51		88			139	

Social Activities

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Religious activities (funerals, naming ceremony, praying, church service)							
AEE (kcal/hour)	35.70	(25.54)	40.04	(34.99)	−4.333	37.23	(29.21)
PAL	1.61	(0.43)	1.79	(0.65)	−0.180*	1.68	(0.53)
Light activity (mins/hour)	49.09	(13.55)	45.02	(15.99)	4.069*	47.66	(14.55)
Moderate activity (mins/hour)	6.14	(4.76)	7.47	(6.87)	−1.333	6.60	(5.61)
Vigorous activity (mins/hour)	0.63	(0.66)	0.72	(0.77)	−0.0869	0.67	(0.70)
Very Vigorous activity (mins/hour)	0.08	(0.14)	0.11	(0.15)	−0.0290	0.09	(0.15)
Observations	155		84			239	

Social Community (chatting with friends, community assembly)							
AEE (kcal/hour)	42.84	(35.35)	46.52	(38.09)	−3.678	43.79	(36.06)
PAL	1.72	(0.57)	1.94	(0.75)	−0.224**	1.78	(0.63)
Light activity (mins/hour)	48.58	(12.52)	47.81	(12.05)	0.768	48.38	(12.39)
Moderate activity (mins/hour)	7.50	(5.93)	8.79	(8.65)	−1.290	7.83	(6.75)
Vigorous activity (mins/hour)	0.58	(0.77)	0.79	(0.70)	−0.212*	0.63	(0.75)
Very Vigorous activity (mins/hour)	0.10	(0.21)	0.13	(0.16)	−0.0340	0.11	(0.20)
Observations	298		104			402	
Survey (responding to the study's questionnaire)							
AEE (kcal/hour)	48.35	(48.57)	50.39	(35.97)	−2.041	49.01	(44.75)
PAL	1.79	(0.75)	2.01	(0.71)	−0.219	1.86	(0.74)
Light activity (mins/hour)	46.50	(12.35)	40.20	(17.34)	6.304*	44.47	(14.38)
Moderate activity (mins/hour)	7.83	(6.65)	8.80	(6.65)	−0.965	8.14	(6.64)
Vigorous activity (mins/hour)	0.90	(2.03)	1.06	(0.95)	−0.165	0.95	(1.76)
Very Vigorous activity (mins/hour)	0.14	(0.27)	0.23	(0.46)	−0.0885	0.17	(0.34)
Observations	80		38			118	

Resting and sleeping

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Resting							
AEE (kcal/hour)	25.23	(40.16)	17.73	(32.64)	7.491*	21.69	(36.97)
PAL	1.42	(0.66)	1.36	(0.67)	0.0616	1.39	(0.66)
Light activity (mins/hour)	45.59	(20.68)	41.77	(24.03)	3.820*	43.79	(22.39)
Moderate activity (mins/hour)	3.86	(6.06)	3.04	(6.40)	0.820	3.47	(6.23)
Vigorous activity (mins/hour)	0.51	(1.13)	0.39	(0.71)	0.116	0.45	(0.96)
Very Vigorous activity (mins/hour)	0.10	(0.28)	0.08	(0.16)	0.0260	0.09	(0.23)
Observations	339		303			642	
Sleeping							
AEE (kcal/hour)	6.73	(16.06)	3.74	(10.25)	2.983***	5.31	(13.69)
PAL	1.11	(0.27)	1.08	(0.21)	0.0377**	1.10	(0.24)
Light activity (mins/hour)	36.14	(27.87)	32.48	(28.75)	3.654*	34.40	(28.34)
Moderate activity (mins/hour)	1.04	(2.61)	0.62	(1.80)	0.429**	0.84	(2.27)
Vigorous activity (mins/hour)	0.15	(0.34)	0.09	(0.26)	0.0593**	0.12	(0.30)
Very Vigorous activity (mins/hour)	0.03	(0.09)	0.01	(0.05)	0.0162***	0.02	(0.08)
Observations	583		526			1109	

Personal activities

	Males		Females			Full sample	
	Mean	SD	Mean	SD	Difference	Mean	SD
Leisure (playing music instruments, watching TV)							
AEE (kcal/hour)	19.04	(19.01)	13.04	(16.11)	5.993	16.87	(18.02)
PAL	1.29	(0.29)	1.26	(0.32)	0.0309	1.28	(0.29)
Light activity (mins/hour)	43.65	(23.72)	32.17	(25.77)	11.48	39.50	(24.75)
Moderate activity (mins/hour)	2.96	(3.41)	1.68	(2.61)	1.276	2.50	(3.17)
Vigorous activity (mins/hour)	0.26	(0.21)	0.46	(0.54)	−0.195	0.33	(0.37)
Very Vigorous activity (mins/hour)	0.08	(0.17)	0.15	(0.23)	−0.0674	0.11	(0.19)
Observations	23		13			36	
Eating							
AEE (kcal/hour)	41.56	(38.44)	60.57	(47.84)	−19.02***	52.28	(44.92)
PAL	1.70	(0.62)	2.22	(0.93)	−0.520***	1.99	(0.85)
Light activity (mins/hour)	47.89	(15.03)	45.89	(12.71)	2.002	46.76	(13.78)
Moderate activity (mins/hour)	6.61	(5.86)	11.69	(11.07)	−5.075***	9.47	(9.50)
Vigorous activity (mins/hour)	0.75	(0.94)	1.20	(1.29)	−0.445**	1.00	(1.17)
Very Vigorous activity (mins/hour)	0.12	(0.24)	0.19	(0.37)	−0.0678	0.16	(0.32)
Observations	127		164			291	
Personal (bathing, hair-care, reading)							
AEE (kcal/hour)	40.40	(56.62)	48.85	(44.47)	−8.456	44.02	(51.82)
PAL	1.66	(0.89)	1.96	(0.86)	−0.302*	1.79	(0.89)

Light activity (mins/hour)	42.04	(20.73)	46.27	(14.41)	−4.231	43.85	(18.37)
Moderate activity (mins/hour)	6.09	(7.07)	8.75	(9.04)	−2.655*	7.23	(8.06)
Vigorous activity (mins/hour)	0.95	(2.33)	0.92	(1.09)	0.026	0.94	(1.90)
Very Vigorous activity (mins/hour)	0.15	(0.52)	0.16	(0.24)	−0.003	0.16	(0.43)
Observations	124		93			217	

Asterisks show level of significance ***= significant at 0.1% level, **=significant at 1% level and *=significant at 5% level.

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