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Filling a dietary data gap? Validation of the adult male equivalent method of estimating individual nutrient intakes from household-level data in Ethiopia and Bangladesh

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ABSTRACT

Many researchers use data from Household Consumption and Expenditure Surveys (HCES) to estimate individual food and nutrient intake when individual dietary data are not available. They assume that food is allocated within households according to members' proportional energy requirements relative to an adult male (called an adult male equivalent, or AME). This study sought to validate AME-based estimates of individual consumption of calories, protein, iron, and animal source protein (ASP) across 10 age-sex categories, using data from Bangladesh and Ethiopia containing both household and individual-level consumption data. The study also assessed the accuracy of adjusting for meal partakers and physical activity levels (PAL), and compared energy-weighted AMEs to nutrient-specific AME predictions.

Energy AME-based predictions of nutrient intake were generally accurate within ten percentage points of individually reported intakes, but were less accurate for infants 6–23 months and children in Bangladesh than for other demographic groups. AME predictions were more accurate: (1) in Ethiopia than in Bangladesh, (2) for predicting intake of the three nutrients rather than ASP, (3) for estimating nutrient intake rather than adequacy, (4) using energy-weighted AMEs rather than nutrient specific weights, and (5) using moderate PAL for youth and adults rather than high PAL. Adjusting for meal partakers did not consistently improve the AME-based predictions. Energy based AME estimates from household data can produce a useful proxy of average intake for certain population subgroups, however individually measured dietary assessment remains the best approach to identify groups at risk of nutrient inadequacy.

1. Introduction

Data that describe a population's food and nutrient consumption and dietary patterns are critical for informing wide-ranging policy, regulatory, programmatic, and advocacy objectives, including: population-level problem diagnosis, surveillance, targeting, planning, evaluation, and global monitoring. Some of this information can be obtained from widely available sources such as annual national food balance sheets, which are, however, limited to providing a picture of foods available for consumption at the national level.

Individual-level dietary intake assessment methods, including observer weighed food records, 24-h intake recalls, and food frequency questionnaires, offer the most scientifically accepted means of quantifying food and nutrient intake. However, many low-income countries have not invested in national dietary assessment surveys, due to perceived (and actual) constraints related to the expense and complexity of the undertaking, as well as a lack of in-country familiarity with the technical processes of dietary data collection and analysis.

A series of efforts are underway to facilitate the collection and use of dietary data in low-income countries[1]. In the meantime, researchers have explored other creative solutions to these data gaps. Household Consumption and Expenditures Surveys (HCES)—also called Household Income and Expenditure Surveys (HIES), Household Budget Surveys (HBS), and Living Standards Measurement Surveys (LSMS)—are

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[1] See the International Dietary Data Expansion Project (INDDEX): http://inddex.nutrition.tufts.edu/; Global Dietary Database: http://www.globaldietarydatabase.org/the-global-dietary-database-measuring-diet-worldwide.html; FAO/WHO Global Individual Food Consumption Data Tool: http://www.fao.org/food/evaluationnutritionnelle/foodconsumptiondatabase/fr/.

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multifaceted surveys widely conducted every 3–5 years on a nationally representative sample to characterize important aspects of household socioeconomic conditions. Though the primary purpose of HCES is to generate data for poverty monitoring, national accounts, and the consumer price index (Smith and Subandoro, 2007), there is growing interest in their utility for food security and nutrition-related objectives (Fiedler et al., 2013; Lividini and Fiedler, 2015; Fiedler, 2014). The food expenditure modules of HCES are constructed to capture the value of household food expenditures, so, by definition, they yield household-level data. One critical, yet under-studied, question is whether (and how) household level data can be used to draw inferences about the food and nutrient intakes of various socio-demographic groups of individuals typically targeted by food security and nutrition policies and programs.

The design of a given HCES informs the degree to which it can be used to calculate household-level dietary metrics. Modules vary greatly from one country to the next, differing across such design features as the recall period, level of detail and composition of the food lists, approaches to capturing food consumed outside the home, whether food consumed by non-household members is recorded, and the degree to which they capture household food consumption rather than just acquisition data (Smith et al., 2014). Though there is still relatively little best-practice evidence to build on, many of the modifications needed to produce more useful household-level food and nutrition metrics from HCES data are likely to be within the reach and mandate of national statistics offices in charge of collecting more accurate estimates of food expenditure. For many purposes, there is also a natural confluence of interest between those who typically design and implement HCES and those who seek to re-purpose this information for better food and nutrition policies and programming (Fiedler et al., 2012; Fiedler, 2013).

While a well-designed HCES can be used to produce household-level information on food and nutrient consumption, an open question is whether household food consumption data can provide valid insight into the consumption behavior of different types of individuals *within* households. HCES have been used to estimate food consumption, apparent nutrient intake and apparent nutrient inadequacy, primarily in the context of food fortification programming, by making a key assumption: that macro- and micronutrients are distributed within a household according to an individual's energy requirements – i.e., that a given 'pot' of household food, whether or not it is nutritionally adequate at a household level, is allocated equitably, according to the relative energy needs of each age-sex group in the household (Fiedler et al., 2013, 2012, 2015; Bermudez et al., 2012). Adult male equivalents (AME), (also known as "adult consumption equivalents", or ACE), express energy requirements on the basis of gender, age, and physiological status as a proportion of the energy requirements of an average adult male (Weisell and Dop, 2012; World Health Organization, 2004). Researchers have applied these AME factors to information about the household's total food or nutrient consumption and demographic composition to calculate the energy available per AME in the household and the apparent proportion of available household food and nutrients consumed by individuals. They then examined intake estimates in relation to requirements to generate nutrient adequacy information for each demographic group.

An extensive economics literature, largely from the late 1980s and 1990s, examines intra-household resource allocation and the implications of intra-household inequalities for policy implementation and impact (Haddad and Kanbur, 1990; Haddad and Kanbur, 1992; Haddad et al., 1995a; Strauss and Thomas, 1995; Behrman, 1988, 1997; Behrman and Deolalikar, 1990). In rejecting a unitary model of the household (Alderman et al., 1995), many of these studies have theorized a number of possible decision rules to explain unequal resource allocation, including a contributions rule, that resources are allocated according to individual contributions to household welfare; and a needs rule (or equity rule) which theorizes that allocations are made according to need in order to maximize distributional fairness (Haddad and Kanbur, 1992).

Many more studies have examined the *equality* of intra-household food distribution (Nelson, 1986; Gittelsohn, 1991; Luo, 2001; Leroy et al., 2008) and dietary diversity (Villa et al., 2011) than the *equity* of nutrient distribution, often finding adult male-biased differentials that depend in magnitude, however, on the socio-cultural and economic context (Gittelsohn and Vastine, 2003).

Empirical examinations of the *equity* of intra-household food and nutrient distribution – that is, studies of distribution relative to need – are rarer, in part because of the challenge of defining 'need' (Bouis and Pena, 1997) (particularly for non-food resources) and in part due to the relative scarcity of quantitative dietary data on multiple members of the same household. One of the first and most often cited studies, by Haddad and Kanbur (Haddad and Kanbur, 1990) of Philippine households, found that energy inequities were significant; the authors calculated the effects of using household data rather than individual-level data on poverty estimates and concluded that neglecting inequities was likely to underestimate poverty levels by 20–40%. Luo (2001) examined inequities in intra-household consumption of several nutrients and food groups in 8 Chinese provinces, finding significant adult and male-biased age and sex differences in the 'fair share' of nutrients consumed.

A recent review by Berti (2012) analyzed 25 studies from 14 countries in Asia, Africa, and Latin American & the Caribbean that reported energy intakes across more than one age-sex category, but many of these studies lacked gender disaggregated data and intake data from all household members. Using reported intakes and requirements, Berti calculated the extent to which these categories of individuals received the share of energy that would have been predicted by the assumption of AME-based intra-household food distribution. Berti found a great deal of variation in the results across studies, with actual allocation conforming to the predicted values in only a handful of cases. However, given that most of the empirical results fell within ± 20% of what was predicted by the distribution rule, the author concluded that this approach might be useful for selecting food vehicles for fortification programs but not for calculating whether individual nutrient intakes vary as a result of a programmatic intervention, suggesting that the criteria for an acceptable level of error depend on the purpose of the estimate.

In a second study, Dary and Jariseta (2012) drew on 2008 survey data from Uganda, containing individual 24-h diet recalls of children 24–59 months and women 15–49 years as well as household food expenditure, with demographic information on the entire household. The authors applied the AME approach to the household data to produce individualized estimates (that is, using household data to estimate individual intake) for the two aforementioned age groups of the quantity consumed of several common fortification vehicles. They compared the results of these predictions to the 24-h recall results in one urban and two rural regions. The authors found that HCES systematically underestimated consumption of fortified foods relative to the 24-h recall module, but concluded that HCES could be a proxy for individual-level data for the purposes of modeling fortification coverage.

Given the dearth of datasets that contain both household and individual-level data on all household members to validate the AME distribution assumption, other authors have aimed to compare the results of AME-predicted intake estimates to those derived from individual dietary intake surveys conducted at different time points on different samples than the HCES data. A study in Bangladesh (Lividini et al., 2013) compared nutrient intake and adequacy estimates (derived by applying the "AME method" to a national household consumption and expenditure survey implemented in 2005), to an observer-weighed food record, frequently considered to be a gold standard for dietary assessment, implemented in two subdistricts in 2007/8. The authors recognized the limitations of using these very different data sets for validation purposes, and instead sought to understand differences in the policy relevance of the types of information provided by the two data sources. Similarly, a study by Jariseta et al. (2012) compared "individualized" Uganda 2006 HCES data (that is, individual food or nutrient intake estimates derived from household-level data) to a 2008 24-h recall survey to determine the extent of convergence in nutrient density estimates for women of reproductive age and children 24–50 months. They found no significant difference between the two methods' estimates of median energy intakes and nutrient densities of protein, fat, fiber, iron, zinc, thiamin, riboflavin, and vitamin B6; however, application of the AME assumption to the HCES data overestimated intakes of vitamins C and B12 and underestimated intakes of vitamin A, folate, niacin, calcium, and zinc in at least one of the groups.

The results of these prior studies suggest that the AME-predicted intake approach, when applied to HCES data, may serve as a valid proxy of individual food and nutrient intake for some age-sex groups in certain contexts. Yet these studies have faced a range of limitations, including lacking truly comparable household and individual-level data, examining only few nutrients (e.g., Berti's review looked only at energy estimates), and assessing AME-based predictions primarily for women and children's intakes rather than across all types of household members. Furthermore, much of this prior validation research has sought to compare results derived from "individualized" HCES data to the results of dietary intake surveys. Though this is a logical approach given that the ultimate question of interest is whether or not HCES data can be used to proxy individual intake, comparing two different types of questionnaire instruments introduces additional 'noise' stemming from their different designs that could also contribute to observed differences in the results. For instance, factors such as differing recall periods in expenditure and dietary modules have hindered the isolation and testing of the underlying assumption that has motivated some researchers to individualize household data – that food in the household is allocated equitably, according to each individual's physiological energy requirements relative to those of other household members.

This study draws on two unique datasets from the diverse socio-cultural contexts of Bangladesh and Ethiopia to assess the accuracy of AME-predicted nutrient intakes from household-level dietary data, compared to nutrient intakes derived from the food preparer's direct report of the proportion of each food item or dish consumed by each household member. A secondary study aim is to determine the degree to which these results are affected by modifying certain key parameters of the AME weights and adjusting household intake estimates for the absence of certain family members at certain meals. The results of this study are intended to inform the future use of HCES data for food and nutrition decision-making objectives.

2. Methods

2.1. Databases

The Bangladesh data used in this study were derived from the third of three panel survey rounds, collected by Tufts University in 2003 as part of the Food Insecurity Measurement and Validation Study funded through the USAID-supported Food and Nutrition Technical Assistance (FANTA) Project (see Table 1). Detailed data collection methods are published elsewhere (Coates et al., 2006). Briefly, 597 rural households were selected for interview through multi-stage cluster sampling with probability proportional to size (PPS) from one Division and five Districts in each of north, central, and southern Bangladesh. The multipurpose questionnaire was administered to males and females, and covered a range of socio-economic, health, nutrition, and food security questions including demographic information for each household member as well as detailed household expenditure data and household and individual dietary data for all household members.

The Ethiopia data used for this study were obtained from the second round of a four-round longitudinal panel study of 1197 rural households in the Oromiya and SNNPR regions of Ethiopia conducted in 2014 during the tail end of the 'lean season' months of September-October. The survey was implemented by Tufts University, in partnership with Jimma and Hawassa Universities, in support of USAID's large-scale, integrated nutrition program, ENGINE. The survey was conducted through interviews with adult males and female respondents in each household, using comprehensive multipurpose questionnaires that included demographic, expenditure, and 24-h dietary recall modules.

Table 1
Sample characteristics (Bangladesh and Ethiopia).

	Year collected	Sample size *(# households with diet records)*	Sample size *(# individuals with diet information)*	Geographic coverage
Ethiopia	2014	1172	6052	2 Regions 9 Woredas
Bangladesh	2003	563	2544	3 Divisions 15 Districts

2.2. Dietary data

In Bangladesh the dietary data were obtained from the primary food preparer through two non-consecutive 24-h quantitative recalls, (of which only the first was analyzed for this study) and in Ethiopia the dietary data derived from a single 24-h recall, also administered to the primary food preparer. The respondents in both Bangladesh and Ethiopia were asked to report all the food that was prepared for the household and the proportion of each item and dish that was consumed by each household member and by guests. In Bangladesh, a household member was defined as someone who lived at least three days of the week in the homestead and ate the majority of meals from the common pot. In Ethiopia, household members were defined as all individuals who lived and took meals together for at least 3 of the 12 months preceding the interview. The approach of eliciting intake estimates of each household member yielded information on the dietary intake of every individual in the household as well as aggregate household-level consumption. The format of the Tufts Bangladesh dietary data module was later replicated by IFPRI in the 2011–2012 Bangladesh Integrated Household Survey (BIHS), which (unintentionally) allowed for potentially useful comparisons between the two sets of results (Sununtnasuk and Fiedler, this issue).

Both surveys used the widely accepted multi-pass method that prompted the respondent to report increasingly more detailed information about food items and mixed dishes consumed by anyone in the household in order to improve accuracy and ease respondent burden (Gibson and Ferguson, 2008). Portion sizes were estimated using a combination of graduated photographs (Ethiopia only), direct weighing, and calibrated local cooking utensils. Data were not collected on food consumed outside the home by individual family members. The Bangladesh survey generated complete dietary data for analysis from 563 households and 2544 individuals (94% of the sample), while in the Ethiopia survey 1172 households comprised of 6052 individuals had complete dietary information for analysis (98% of the sample).

2.3. Processing of dietary data

Single food items and mixed dishes reported by respondents were recoded to match the closest corresponding food item (or mixed dish, where relevant) in the Food Composition Table (FCT). The Bangladesh dietary data were processed in 2006 with an FCT developed by the Bangladeshi research firm, Data Analysis and Technical Assistance, Ltd (unpublished), which integrated data from the Indian National Institutes of Nutrition FCT and the US Department of Agriculture's National Nutrient Database for Standard Reference (ARS USDA, 2015), along with nutrient information for Bangladesh-specific foods supplied by Helen Keller International. The Ethiopia data were processed using the 1998 food composition database published by the Ethiopian Health and Nutrition Research Institute and FAO, which contained nutrient information for food items as well as common mixed dishes (Ethiopian Health and Nutrition Research institute, 1998). Before linking to the FTC, all information was adjusted for edible portion and yield factor from cooking where needed. Reported portion sizes were standardized through systematic conversion to grams and, for foods assessed volumetrically, to milliliters. Volumetric data were further converted into grams by applying each food's specific gravity factor (Charrondiere et al., 2012).

2.4. Estimation of nutrient requirements

Demographic information on age, sex, and physiological status of each household member (pregnancy status for Ethiopia and Bangladesh, lactation status for all Bangladesh sample females and for the female respondent in Ethiopia) were used to calculate nutrient requirements. For analysis purposes, individuals were grouped into five policy-relevant age categories and further disaggregated by sex: infants (m/f, 6–23 months), children (m/f, 24–59 months), youth (m/f, 5–17 yrs), adults (m/f, 18–65 yrs), and elderly (m/f, > 65 yrs).

The estimated average daily energy requirements for each group were based on FAO/WHO/UNU normative guidance figures for healthy, well-nourished individuals, and were adjusted for pregnancy and lactation status (World Health Organization, 2004). Estimated average requirements (EARs) for protein were derived from WHO/FAO guidance, and were also adjusted for pregnancy and lactation status (World Health Organization, 2007). Iron requirements were derived from the EAR recommended by WHO/FAO (World health Organization, 1998) and were adjusted for bioavailability, which was assumed to be 10% across all demographic groups as suggested by WHO/FAO for developing country diets comprised primarily of staples and vegetables with little meat. Per the guidance, an additional 39.6 mg were added to requirements for pregnant women and additional 11.7 mg were added to requirements for lactating women.

2.5. Calculation of adult male equivalent weights

Adult male equivalent weights (AMEs) were calculated for each age-sex category for energy, protein, and iron. To do this, nutrient requirements for each individual were divided by the requirements of an adult male age 18–29.9 years in order to obtain a specific AME weight for that individual. The AME weights for all individuals in the dataset were later averaged to create estimates for ten age-sex categories for presentation purposes.

Predictions of the distribution of household food and nutrients among members are likely to be sensitive to the AME weights used. The construction of AME weights requires decisions about which standards to use in deriving the relative nutrient requirements of the different demographic groups, whether to use energy-based AMEs or nutrient-specific AMEs in predicting intake of nutrients such as protein or iron, and whether to adjust the assumptions about intake for meals in which certain household members did not participate. This section describes steps taken to assess the robustness of the AME weights used in this analysis. In constructing AME weights for energy, we used the FAO/WHO (2004) energy requirements, which assume moderate levels of physical activity; we were unable to create sample-specific AME weights adjusted for activity level, as we lacked physical activity level (PAL) estimates for each household member. Thus all primary analyses in the paper assume moderate PAL, but a sensitivity analysis was performed to determine whether and how individual-level energy intake predictions based on AME would be affected by assuming high physical activity levels for household members between ages 5 and 65. These results are available as online supplementary material.

Previous studies using AME assumptions to ‘individualize’ household consumption data have derived AME weights from energy requirements when predicting intakes for specific nutrients (Bermudez et al., 2012; Fiedler et al., 2015), based on the assumption that calories come closest to reflecting the quantities of food as perceived by household members, and that micronutrient content is invisible to them. Table 2 illustrates the substantial differences across AME weights calculated based on energy, protein, and iron requirements. An infant (6–23 months), for example, needs about 28% of the calories required by an adult male, but that same infant requires over half (53%) of the iron required by an adult male. For all age/sex groups, the relative proportion of iron need compared to that of an adult male is much higher than is the case for calories. Thus if iron-containing foods are distributed according to calorie AMEs, those groups with higher relative iron needs will be at a disadvantage. We hypothesize that households are more likely to gauge distribution based on the relative amount of staple food needed by each household member to feel satiated. If households were to follow this decision rule, then using proportionate energy requirements to predict proportionate individual intakes of all nutrients should be more accurate than using proportionate micronutrient requirements to predict proportionate intake of a specific micronutrient (i.e., using an iron AME weight to predict individuals' iron intake from household data). To test this hypothesis, we calculate results for iron and protein AME-based predictions using both calorie-weighted AMEs and nutrient-specific (iron or protein-weighted) AMEs.

In the case of Bangladesh, additional AMEs were calculated to adjust for meal partakers. Weights were created for the three primary daily eating occasions based on the average proportion of macro and micronutrients consumed during that meal across the sample, with respect to individuals who consumed all three meals. Separate meal weights were created for energy, protein and iron to account for macro and micronutrient differences in meal composition across mealtimes. Individuals who were away from the home during the course of a meal, and those reporting fasting, were treated as non-meal partakers, and their caloric needs in terms of the distribution of calories within the household were reduced by the percentage contribution of the various macro and micro nutrients supplied by that meal on average. Individuals who reported not eating because food was not available

Table 2
AME weights based on calorie, protein, and iron requirements.

1	2	3	4
Age/sex category	Average energy AME weight by age-sex group[1]	Average protein AME weight by age-sex-group[2]	Average iron AME weight by age-sex group[3]
Infants (6–23 months)	0.28 (0.0)	0.21 (0.0)	0.53 (0.1)
Male	0.29 (0.0)	0.22 (0.0)	0.53 (0.1)
Female	0.27 (0.0)	0.21 (0.0)	0.53 (0.1)
Children (24–59 months)	0.39 (0.0)	0.26 (0.0)	0.56 (0.1)
Male	0.41 (0.0)	0.27 (0.0)	0.57 (0.1)
Female	0.38 (0.0)	0.25 (0.0)	0.56 (0.1)
Youth (5–17 yrs)	0.73 (0.2)	0.67 (0.2)	0.99 (0.3)
Male	0.78 (0.2)	0.68 (0.3)	0.98 (0.2)
Female	0.68 (0.1)	0.65 (0.2)	1.00 (0.3)
Adults (18–65 yrs)	0.90 (0.1)	1.02 (0.1)	1.16 (0.4)
Male	0.97 (0.0)	1.05 (0.0)	1 (0.0)
Female	0.82 (0.1)	1.00 (0.1)	1.31 (0.6)
Elderly (> 65 yrs)	0.75 (0.1)	1.01 (0.1)	0.92 (0.1)
Male	0.80 (0)	1.08 (0)	1 (0.0)
Female	0.69 (0)	0.92 (0)	0.83 (0.0)

Calculated from:
[1] World Health Organization, Food and Agriculture Organization of the United Nations, University UN. Human Energy Requirements. Food and Nutrition Technical Report Series, 2004.
[2] World Health Organization, Food and Agriculture Organization, University UN. Protein and Amino Acid Requirements in Human Nutrition. WHO Technical Report Series 935, 2007.
[3] World Health Organization, Food and Agriculture Organization. Vitamin and Mineral Requirements in Human Nutrition, 2nd Edition. Report of a joint FAO/WHO expert consultation, Bangkok, Thailand, 21–30 September 1998, 2004

were not adjusted downward, to reflect the reality of macro and micronutrient scarcity in the household. Reasons for not taking meals were not available for the Ethiopia data, thus these data were unadjusted. All Bangladesh analyses were run using both unadjusted AMEs and AMEs adjusted for meal partakers to assess the extent to which the adjustments affected the convergence of the AME-based predictions with those from the food preparer's direct report.

2.6. Calculation of individually reported and AME-predicted nutrient intake

Individual-level nutrient intakes of energy, protein, animal source protein, and iron were calculated using two different methods for the purpose of assessing the convergence of the results. Individually reported intakes, i.e. those derived from the report of the food preparer, were considered to be the standard of accuracy for this study. These intakes were calculated by totaling the nutrient content for all foods reportedly consumed by each individual in each household in the previous 24 h. "AME-predicted" nutrient intake was calculated by multiplying each individual's AME weight by the total amount of the nutrient consumed by the household, to derive the predicted proportion consumed by each household member.[2]

2.7. Estimates of individually reported and AME-predicted nutritional adequacy

Estimates of nutritional adequacy were calculated using both individually reported and AME-predicted intakes, in order to assess the degree to which the two approaches identified the same proportion of the population as nutritionally adequate. Adequacy calculations for energy and protein were performed by using the EAR cut-point method to calculate the proportion of the population with intakes below the median requirement (IOM, 2000). Though the EAR cut-point method is not optimal for calculating average energy adequacy when energy requirements are correlated with intake (IOM, 2000), it was used for assessing energy adequacy as there is no other widely accepted, survey-based, alternative. Protein requirements are considered normally distributed and are largely uncorrelated with intake, thus meeting the primary criteria for applying the EAR cut point method for assessing adequacy (IOM, 2000). Iron requirements are not normally distributed, particularly for menstruating women and young children, thus the EAR probability method was used. Probability intake measures, published by the Institute of Medicine (IOM, 2001) were used to assign probabilities of inadequacy, which were then used to calculate the proportion of the population at risk of nutritional inadequacy using the approach described by the Institute of Medicine (IOM, 2000).

2.8. Socio-demographic variables

Female education level is the number of years of schooling completed by the wife of the household head or the household head herself in the case of female-headed households. Dependency ratio adhered to the World Bank definition (World Bank), which is the ratio of presumed dependents (younger than 15 years or older than 64) to the working-age population (those 15–64). Household composition was examined as the average percentage of total households members represented by each demographic category. A wealth index was constructed by summing binary responses to questions of types of durable goods owned by the household, with a range of 0–17 for Ethiopia and 0–36 for Bangladesh. In Bangladesh, food insecurity was measured using the Food Access Survey Tool (Coates et al., 2003), a Bangladesh-specific precursor to the Household Food Insecurity Access Scale (Coates et al., 2007), which was administered in the Ethiopia survey. Both scales have a range of 0–9 when constructed by summing the binary responses to each food insecurity experience question.

2.9. Analysis

For each of the ten demographic groups in both Bangladesh and Ethiopia, individually reported intakes of energy, protein, animal source protein, and iron were calculated as a percentage of AME-predicted intakes to determine the degree of convergence of the AME-predicted intake method with the standard; individual report was assumed to be closer to the true value of intake than that predicted using AME weights. Predictions that come closer to individually reported amounts are considered to be more accurate, or correct.

In order to understand the potential implications of poor convergence of the AME-predicted values, we also determined the proportion of the population that would be assessed as 'at risk of inadequacy' using the AME-predicted intake method compared to the individually reported intake approach. These cut points are used in the present analysis as a means of identifying individuals at risk of inadequate intake, based on the probability that their intake relative to the EAR correctly identifies that risk. It is not possible to assess individual nutrient requirements from survey data, so using these cut points is the most reasonable alternative. Finally, we examined the degree to which the AME-predicted method incorrectly classified individuals as nutritionally adequate and inadequate (errors of exclusion and inclusion, respectively), and the percent of each group correctly classified, where "correct" is the individual report. Across the demographic groups and nutrients, each of these variables was assessed using different AME parameters: (1) energy AME weights, (2) nutrient-specific AME weights, and (3) AME weights adjusted for meal partakers (Bangladesh only).

3. Results

Table 3 compares the household characteristics of the Bangladesh and Ethiopia samples. Ethiopian households were larger, with a higher percentage of female-headed households (by self-report). Adult females had a lower level of education in Ethiopia. Ethiopian households in the sample were less likely to be highly food insecure and more likely to be food secure. The age distribution of household members also differed, with Ethiopian households having fewer elderly members and adults, and more youth, children, and infants.

3.1. Accuracy of using AME assumptions to estimate individual consumption and adequacy

The following sections present a comparison of AME-predicted intake and adequacy of energy, protein, and iron to individually reported intake and adequacy for the same nutrients. When the method of deriving intake is not specified in the narrative, it is the individually reported amount.

3.1.1. Energy

Fig. 1a compares AME-predicted intake of energy to individually reported intakes for Bangladesh and Ethiopia, with the standard error of the measurement (SEM) indicated with error bars. In Bangladesh, the mean AME-predicted amounts were close to mean individually-reported intakes (i.e., within ± 10 pp.) for most groups of household members, with one notable exception: the AME estimates were substantially greater than the energy intake of infants (by between 32 and

[2] Breast milk consumption was not captured either in the reported intake or in the AME-predicted intakes. As such, reported intake method is likely to *under*estimate true energy and protein intake for infants (particularly those on the younger end of the 6–24 month age range). The AME-predicted method assumes that more of the family food is going to the child than actually would be the case because some of the child's energy and protein needs are being met through breastfeeding, tending to *over*estimate adequacy. For this reason, we expect higher levels of divergence in the reported and predicted intakes among this age group. Resolving this issue would require adjusting for breast milk intake, which was not possible to do for this study.

Table 3
Socio-demographic characteristics; Bangladesh and Ethiopia.

	Bangladesh	Ethiopia
	(n = 563)	(n = 1172)
Female-headed (%)	3.8	10.8
Education level of adult female (mean yrs, sd)	4.9 (3.6)	1.1 (2.2)
Dependency ratio (mean, sd)	4.5 (1.8)	1.1 (0.8)
Wealth score (median, 0–35 Bangladesh; 0–17 Ethiopia]	5.0	9.0
Food insecurity score (median) [0–9]	7.0	4.0
% with score of 0	1.1	26.5
% with score of 1–3	25.5	21.3
% with score of 4–6	17.2	33.5
% with score of 7–9	56.2	18.7
Household size (mean, sd)	4.5 (1.8)	5.6 (2.1)
Average % of total HH members comprised of:		
Infants (6–23 months)	2.9	3.5
Male	1.2	1.9
Female	1.7	1.6
Children (24–59 months)	6.3	9.2
Male	3.1	4.5
Female	3.1	4.8
Youth (5–17 yrs)	30.9	41.0
Male	16.2	21.4
Female	14.7	19.5
Adults (18–65 yrs)	55.1	44.0
Male	26.9	22.5
Female	28.2	21.5
Elderly (> 65 yrs)	4.9	1.3
Male	2.7	0.7
Female	2.1	0.6

reported adequacy in Bangladesh and Ethiopia, respectively; more specifically, the figures depict the percentage of each of the sample subgroups that is energy inadequate by the self-reported measure that is classified as adequate by the AME-predicted method (error of exclusion) and the percentage that is energy adequate by the AME-predicted method that is classified as inadequate by self-report (error of inclusion). The third variable in the figure depicts the percentage of each sample subgroup in which the AME-predicted method classifies according to the individually reported results ("correctly identified").

Over 17% of apparently inadequate infants in the Bangladesh sample were categorized as adequate by the AME-based method but not by self-report, while between 55% and 75% (male and female) of those infants with apparently adequate consumption were categorized as inadequate by the AME approach. Energy adequacy based on individually-reported intake was reached by 84% or more of household members with the exception of infants under two, of whom only about 58% achieve adequacy – not accounting for breastfeeding (data not shown). The overall proportion of the sample correctly classified was below 80% for infants and children but hovered just above 80% for the remaining groups. Errors of exclusion were much lower overall than errors of inclusion in this comparison.

In the Ethiopian case, errors of exclusion were very low, under 10%, for all demographic groups and, while the errors of inclusion were over one third for every age/sex category – close to or over half for children and youth, and over 80% for infants – this finding is also related to the fact that only a very small proportion of the Ethiopian sample – between about 8% and 20% – actually achieves caloric adequacy (based

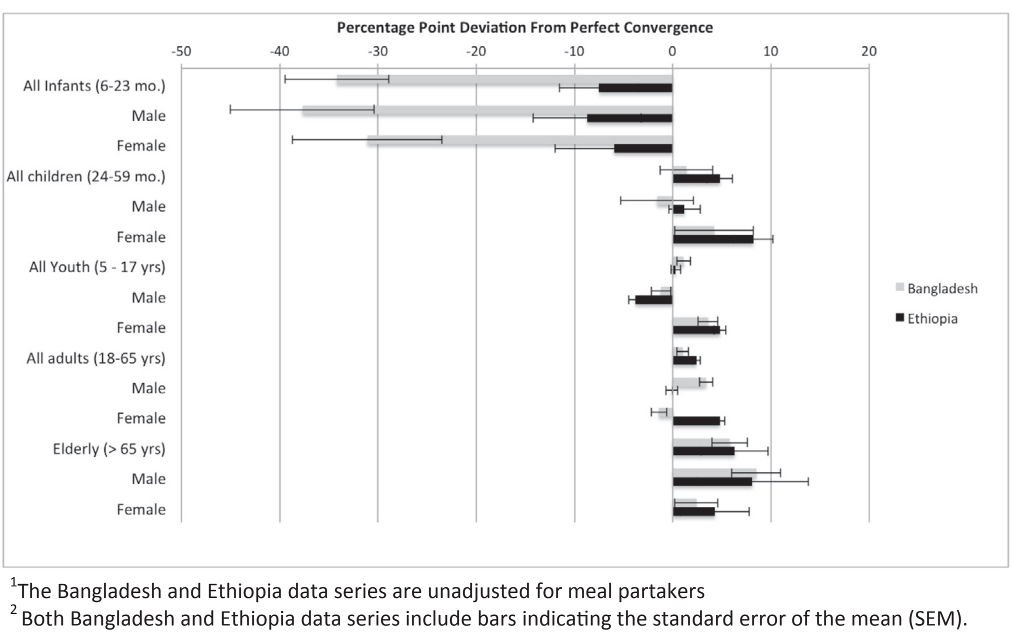
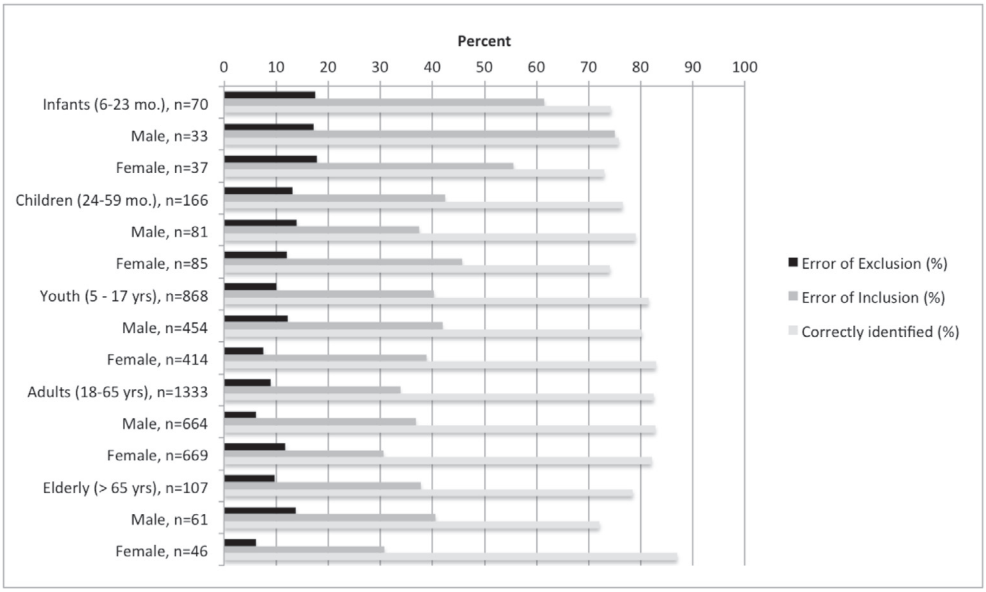


Fig. 1a. Individually reported energy intake as a percent of AME-predicted energy intake: Bangladesh and Ethiopia.[1,2]

38 pp.) relative to individual report. The AME-predicted approach also underestimated intake by male elderly individuals in Bangladesh [8.5 pp. ± 2.5 (SEM)]. Because breast milk could not be accounted for, lack of convergence between the two approaches was expected. Both approaches capture a lower proportion of actual intake for this age group than for others by counting only non-breast milk foods. Therefore, the individual measure would underestimate intake by counting only non-breast milk intake, while the AME approach would overestimate intake by assuming that the infant's proportional requirements need to be filled only by non-breast milk foods. In the Ethiopian sample, the AME-based method predicted energy intake within 10 pp. of reported intake for all age groups, *including* infants and children.

Figs. 1b and 1c present results for AME-predicted vs. individually-reported intake). The overall percentage correctly classified was over 80% for all categories except female infants and over 90% for youth, adults, and elderly. Collectively, the data in Figs. 4a–4c suggested that when the AME-based assumptions were used rather than direct report to predict energy intake and adequacy, the risks of misclassification varied by region and demographic group and by type of misclassification, with higher overall accuracy and lower overall misclassification in Ethiopia than Bangladesh.

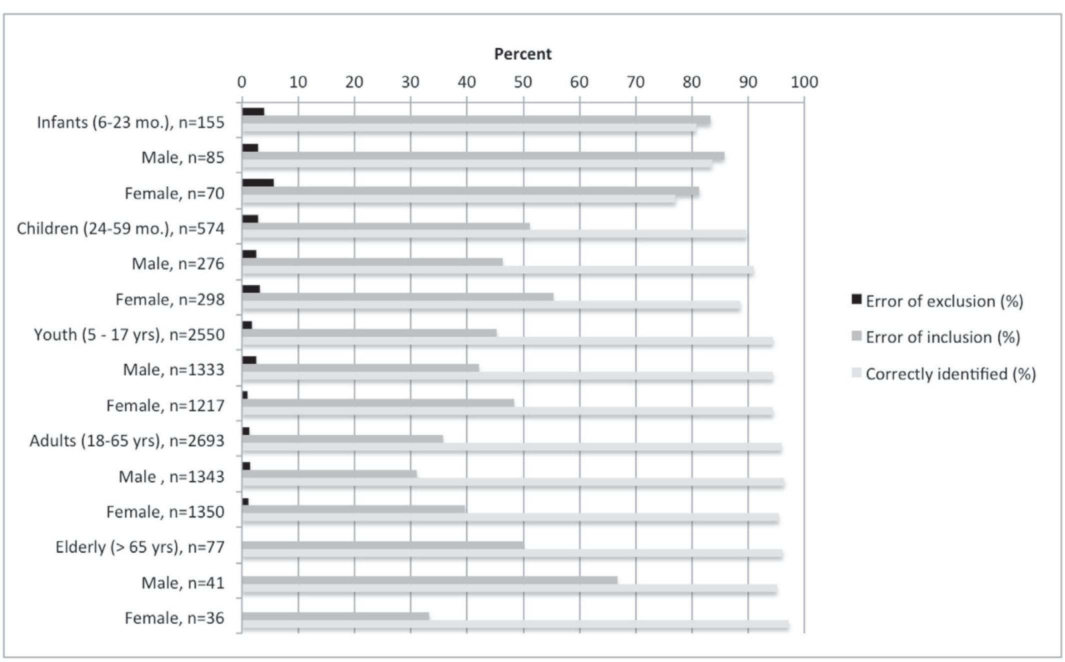
The aforementioned results assume moderate physical activity levels for all individuals in the household, as individual-level data on physical activity were not available in this data set. A sensitivity assessment that assumed high PAL for individuals between 5 and 65 years showed that modifying the AME weights affects the results differently



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2]Error of exclusion = energy inadequate by the self-reported measure but classified as adequate by the AME-predicted method; error of inclusion= energy adequate by the AME-predicted method but classified as inadequate by the AME-predicted method; correctly identified= AME-predicted method classifies according to the individually reported results.

Fig. 1b. Individually reported versus AME-predicted energy adequacy in Bangladesh: errors of exclusion and inclusion, and percent correctly identified.[1,2]

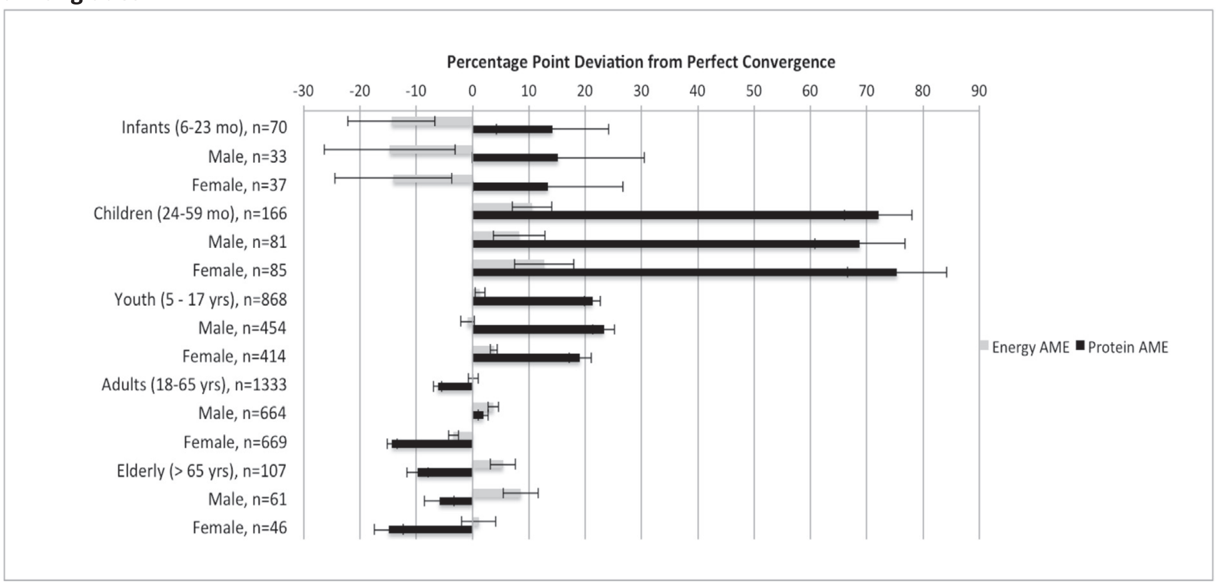
by age category (see online supplementary material). In Ethiopia, the moderate and high PAL-weighted AME predictions were within 2–3 pp. of each other in all cases except for children and adult males. AME-predicted intakes for adult males were just 0.1 pp. different from individually reported intakes when assuming moderate levels of physical activity. When high levels of physical activity were assumed, the high PAL-weighted AME overestimated energy intakes by 5.8 pp., a 5.7 pp. difference in divergence from the individually reported result. Predicted energy intakes for children were dramatically affected by assumptions about physical activity levels; assuming moderate PALs for the whole household in constructing AMEs produced predictions of child energy intakes that were much closer to individually-reported child intakes (underestimate of 4.8 pp. ± 1.3) than the child intake estimates that result from weighting AMEs with high PALs for youth and adults (underestimate of 21 pp. ± 1.5, a 16.2 pp. greater divergence from the individually reported intakes). The Bangladesh results were remarkably similar to this Ethiopia pattern; the high PAL-weighted calculation produced a greater overestimate of calorie intakes



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2]Error of exclusion = energy inadequate by the self-reported measure but classified as adequate by the AME-predicted method; error of inclusion= energy adequate by the AME-predicted method but classified as inadequate by the AME-predicted method; correctly identified= AME-predicted method classifies according to the individually reported results.

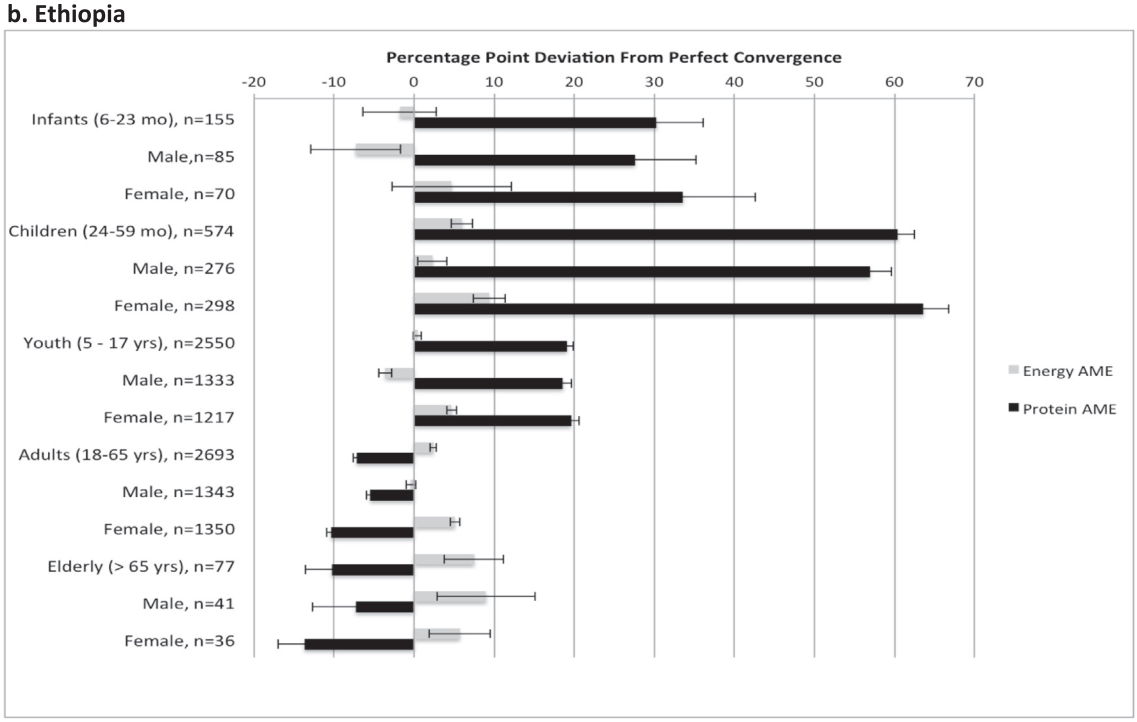
Fig. 1c. Individually reported versus AME-predicted energy adequacy in Ethiopia: Errors of exclusion and inclusion, and percent correctly identified.[1,2]

a. Bangladesh



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2] Both Bangladesh and Ethiopia data series include standard error bars

b. Ethiopia



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2] Both Bangladesh and Ethiopia data series include standard error bars

Fig. 2a and 2b. Individually reported protein intake as a percent of AME-predicted protein intake, using energy v. protein AMEs, Bangladesh and Ethiopia.[1,2]

for adult males (by 5.1 pp.) than those based on moderate PAL, and produced even greater underestimates for children (a divergence that was 16.2 pp. greater than that from the moderate AME estimates). For both adult males and children in Ethiopia and Bangladesh, using moderate PAL parameters to calculate the AME predictions yielded results that were more convergent with individual report than using high PAL parameters.

3.1.2. Protein

One of the questions this analysis sought to answer was whether households distribute calories more equitably than other nutrients, with implications for whether energy AME weights or nutrient specific AME weights are more appropriate to estimate individual nutrient intakes from household data. To assess this question, the study compared the results obtained using nutrient-specific AME weights to estimate nutrient intake to those obtained using energy AME weights. Figs. 2a and 2b depict the percentage point deviation of AME-predicted protein intakes from individual-reported protein intakes using both protein AME weights and energy AME weights to estimate protein intake in Bangladesh (2a) and Ethiopia (2b). Proportionally, protein requirements are relatively lower than calorie requirements for infants and (by a greater amount) children, so assuming allocation according to protein AME implies a smaller likelihood of achieving adequacy than using the energy AME. Relative protein requirements for adults and the elderly are higher; using the protein AME was expected to result in higher intake estimates than if the energy AME weights were used for these groups.

Using the energy AME weights to predict the allocation of protein among household members improved the convergence of AME predictions with individual report. In the Bangladesh survey, the energy AME-based prediction of protein intake diverged from individual report by less than 10 pp. for youth, adults, and elderly. The mean energy AME-predicted protein intakes of male and female children combined was underestimated by 10.6 pp. ± 3.5 (SEM), while the energy AME-based predictions of protein intake *over*estimated the protein intake of infants under two by more than 10 pp., making these results fairly consistent with the Bangladesh results for dietary energy presented in Fig. 1a.

By comparison, the Bangladesh *protein* AME-based predictions *under*estimated the mean protein intake of infants, children, and youth by more than 10 pp., and *over*estimated the protein intake of adult and elderly females by more than 10 pp., making them less convergent with self-reported results, consistent with the bias that would be expected given the differences in relative protein and calorie AMEs. For Ethiopia, the pattern is fairly similar to that of the Bangladesh sample; using the energy AME weights results in a more accurate prediction of individual intakes than using the protein AME weights. In the Ethiopia sample, for all demographic groups the mean protein intake predictions using energy AME weights fell within a ± 10 pp. deviation from the reported intakes. However, the infant and elderly male group estimates had a margin of error suggesting that the true population average divergence could be as high as 15 pp. [infant males = −7.3 pp. ± 5.6 (SEM); elderly males = 9 ± 6.1 (SEM)].

Figs. 2c–2f demonstrated that errors of exclusion and inclusion also differed depending on the AME weights used; in Bangladesh (2c and 2d), use of the energy AMEs resulted in greater errors of exclusion, while use of the protein AMEs resulted in greater errors of inclusion. Errors of exclusion for energy AMEs were greater than 10% for infants, children, and youth. Errors of inclusion for energy AMEs were slightly greater than 20% just for infant males (20.4%) and female children (21.4%). With the exception of male infants and female children, in Bangladesh at least 80% of each age/sex group was correctly classified using energy AME-based predictions, reflecting higher predictive accuracy using the energy AMEs to predict protein adequacy than using protein AMEs.

As in Bangladesh, errors of exclusion in the Ethiopia sample (2e and 2 f) were higher using the energy AME weights than the protein AME weights for all groups except adults and elderly. Using the energy AME weights, almost 50% of apparently inadequate infants under two were misclassified as adequate, compared with 25% using the protein AME weight (though the protein AME weighted prediction also had high errors of exclusion). The rate of such exclusion errors was three times as high for children two to five years old as well: 26 percent were incorrectly categorized as adequate using the energy AME weight compared with about 8 percent using the protein AME weights.

That said, the overall proportion correctly classified as protein adequate or inadequate for all groups except infants in Bangladesh and Ethiopia was above 80% and 90%, respectively, regardless of which AME weights were applied. Additional comparisons of energy-weighted vs. nutrient-specific AMEs for animal source protein and iron consistently demonstrated that the energy AMEs predicted intake and overall classification accuracy as well as or better than the nutrient specific option. The remainder of the paper presents results using energy AME weights.

3.1.3. Animal source protein

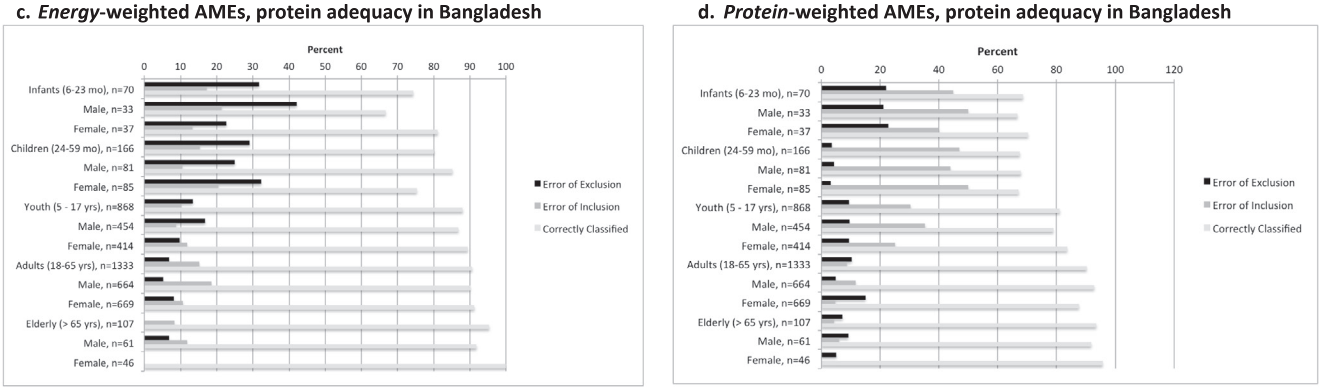
Consumption of animal-source protein (ASP) is important for growth in young children; it is also a luxury in many low-income settings, and we considered it possible that animal source food, as a (presumably) preferred food source, could be distributed differently from protein as a whole. Fig. 3 shows how the assumptions of distribution according to the AME for energy affected the accuracy of estimates of consumption of protein from animal sources, compared to consumption as directly reported among households that reported consuming any animal protein. Once non-ASP consuming households were excluded, the sample sizes for infant and elderly subgroups were unacceptably small, resulting in unstable estimates with very high standard errors. For that reason, we have excluded these two groups from this particular analysis.

The proportion of households consuming any animal-source food was 87% in Bangladesh, where fish is widely consumed, but only 28% in Ethiopia (data not shown). The energy AME-weighted prediction results in dramatic underestimates of ASP intake of children in Bangladesh, [by 48.9 pp. ± 16 (SEM)]. For comparison, the accuracy of *total* protein intake predictions for infants in Bangladesh was closer to individual intakes using energy or protein AMEs (about 15 pp. ± 7.5 [SEM]), and for children (11 pp. ± 4 [SEM] using energy AMEs). The energy AME-weighted prediction also yielded convergent ASP results with the self-reported results for youth and adults, though the AME prediction overestimated ASP intake in adult females and underestimated it in adult males.

In Ethiopia, mean energy AME-based predictions of ASP intake were within 10 pp. of the reported value for youth, adults, and male children;

c. ***Energy*-weighted AMEs, protein adequacy in Bangladesh**

d. ***Protein*-weighted AMEs, protein adequacy in Bangladesh**

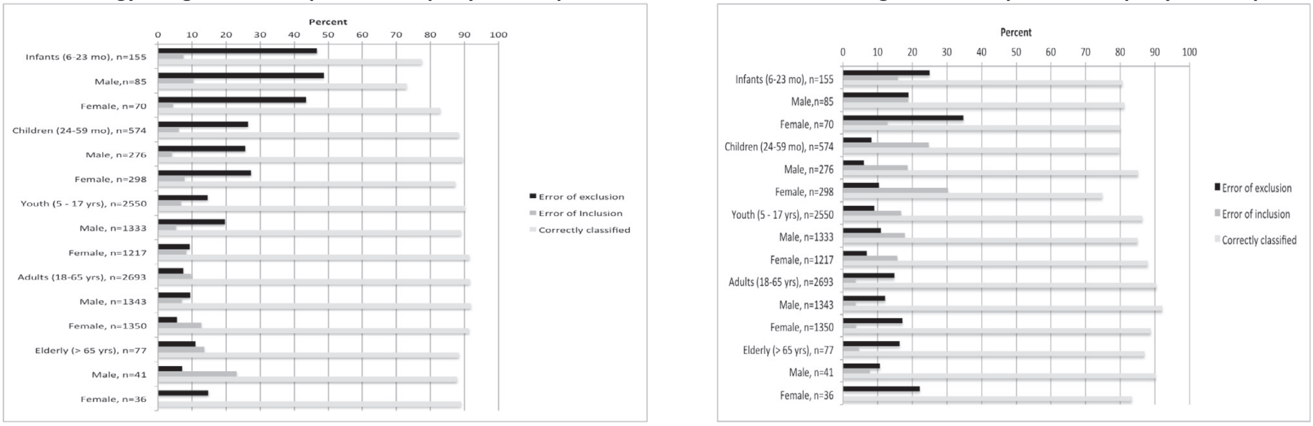


[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers

[2]Error of exclusion = energy inadequate by the self-reported measure but classified as adequate by the AME-predicted method; error of inclusion= energy adequate by the AME-predicted method but classified as inadequate by the AME-predicted method; correctly identified= AME-predicted method classifies according to the individually reported results.

Fig. 2c and 2d. Convergence in classification between individually reported and AME-predicted *protein* adequacy in Bangladesh, using energy-weighted vs. protein-weighted AMEs.[1,2]

e. *Energy*-weighted AMEs, protein adequacy in Ethiopia **f. *Protein*-weighted AMEs, protein adequacy in Ethiopia**



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2]Error of exclusion = energy inadequate by the self-reported measure but classified as adequate by the AME-predicted method; error of inclusion= energy adequate by the AME-predicted method but classified as inadequate by the AME-predicted method; correctly identified= AME-predicted method classifies according to the individually reported results.

Fig. 2e and 2f. Convergence in classification between individually reported and AME-predicted *protein* adequacy in Ethiopia, using energy-weighted vs. protein-weighted AMEs.[1,2]

with the mean AME predictions for female children deviating most from individual-reported ASP intake by 14.8 pp ± 9.5 (SEM)]. This was a similar pattern to the energy AME-based predictions for total protein in Ethiopia, suggesting that these ASP foods are allocated similarly to other protein sources, with no evidence of gender bias against women or girls (though consumption of ASP was low in all age/sex categories).

3.1.4. Iron

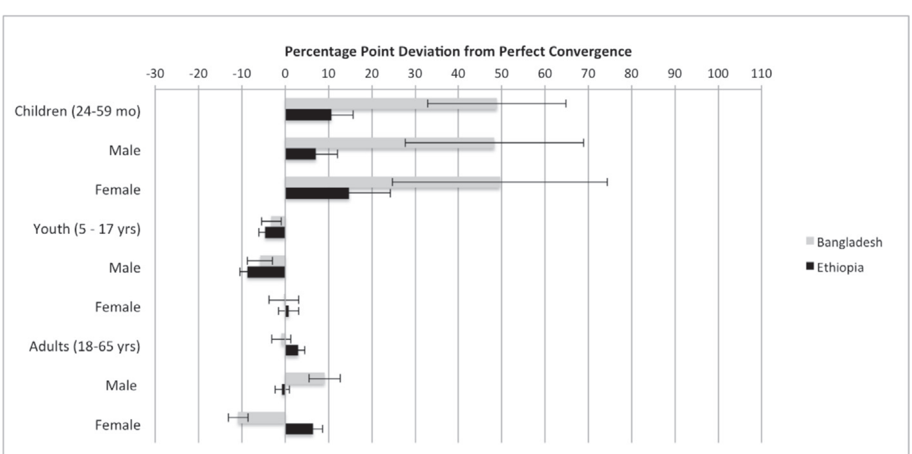
Fig. 4a compares AME-predicted intakes of iron to individually reported intakes for Bangladesh and Ethiopia, using the energy-weighted AMEs. The AME predictions in Bangladesh overestimated individually reported infant iron intake by far more than 30 pp. The predictions were better for other groups, with individual report as a percent of the AME-prediction falling within 10 percentage points of perfect correspondence for all groups except for elderly males, whose iron intake was underestimated by energy AME predictions by 11.4 pp. [± 3.4 (SEM)]. By contrast, in Ethiopia the mean AME predictions fell within 10 pp. of self-report for all groups, including infants.

Figs. 4b and 4c present the classification accuracy of iron adequacy in Bangladesh and Ethiopia, respectively. In the Bangladesh sample, iron adequacy was exceedingly low as assessed by individually reported consumption. In no age/sex group did more than 11 percent reach iron adequacy (data not shown). As a result, the proportion of the population correctly classified as inadequate or as adequate in iron was quite high: over 90% for all groups, but this is primarily an artifact of the very low proportion achieving iron adequacy in the Bangladesh sample. Simply assuming that everyone in the sample is inadequate in iron would have done just as good a job of categorizing the household members correctly.

In Ethiopia, energy-AME-predicted iron intakes fell within 10 pp. of individually reported amounts for all groups, including infants. The error of exclusion for all groups using energy AME weights were greater than 30% for all groups except female youth and adults, but errors of inclusion were quite low for all groups. Overall, the percent correctly classified as adequate or not was greater than 90% for all groups but infants.

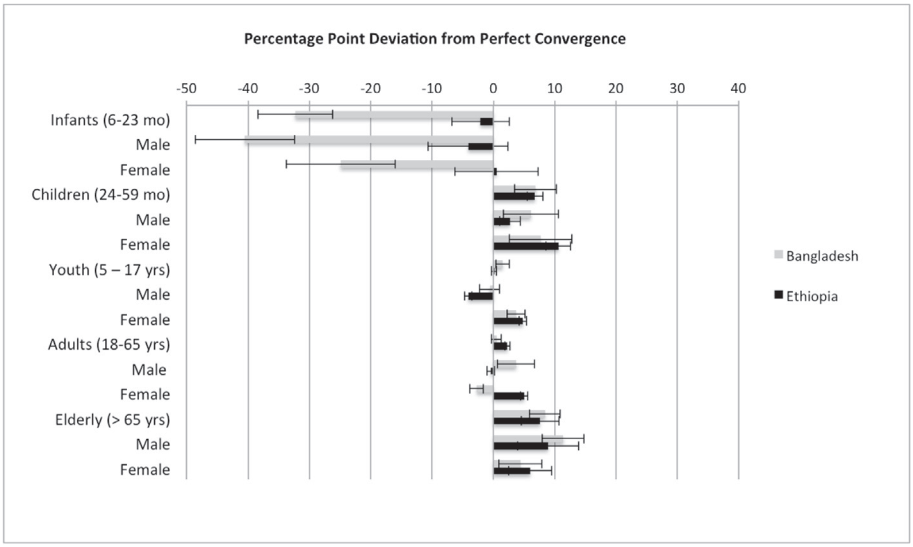
3.1.5. Adjusting for the number of meal partakers

The Bangladesh data set contained information on the number of household members present at each meal. This information allowed us to determine the degree to which the previous results would be affected by adjusting intake and adequacy for the number of meal partakers. Note, though, that the adjustments were made only to estimated adequacy of the food consumed *in the household*; data did not permit estimating consumption of food consumed away from home by those who were not present at the meal.



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2] Both Bangladesh and Ethiopia data series include standard error bars
[3] Includes only households with nonzero consumption of animal food

Fig. 3. Individually reported *animal source protein* intake as a percent of AME-predicted *animal source protein* intake, based on energy AME; Bangladesh and Ethiopia.[1,2,3]



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2] Both Bangladesh and Ethiopia data series include standard error bars

Fig. 4a. Individually reported *iron* intake as a percent of AME-predicted *iron* intake, using energy-weighted AMEs, Bangladesh and Ethiopia.[1,2]

Table 4 shows how the estimated risks of inadequate consumption of energy, protein, and iron were affected when adjusted for the number of members consuming each meal. Our expectation was that adjusting for meal partakers would increase the accuracy of estimates of inadequacy (those falsely classified as adequate, and those falsely classified as inadequate), but this hypothesis was not borne out by the data. In general, the percent of consumers incorrectly predicted to be adequate in calories (error of exclusion) was consistently higher after adjustment for meal partakers, while the percent incorrectly assumed to be apparently inadequate (error of inclusion) was lower after making this adjustment.

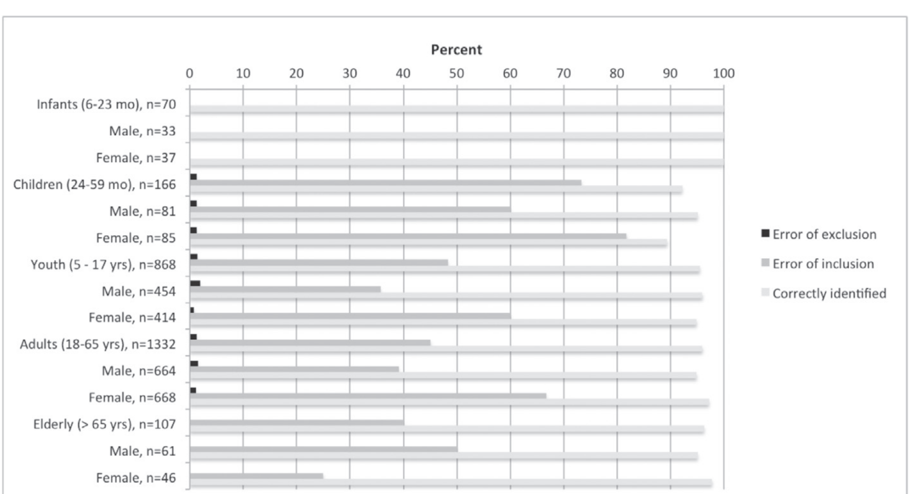
For protein and iron, adjusting for meal partakers only slightly affected the percent incorrectly assumed by AME-based predictions to be adequate or inadequate, and any differences were not in a consistent direction. Adjusting for meals missed did not appear to improve the accuracy of estimated prevalence of deficiency in this sample.

3.1.6. Accuracy of AME Predictions: Summary

Tables 5.1 and 5.2 summarize the accuracy of energy AME predictions of energy, protein, ASP, and iron intakes (5.1), and the extent of errors of exclusion and accurate categorization with respect to energy, protein, and iron adequacy (5.2).

The majority of AME-predicted intake estimates come within ten percentage points of accurately predicting the individually reported consumption levels (Table 5.1), with the results differing slightly between Ethiopia and Bangladesh; the AME predictions functioned better in Ethiopia with respect to energy, protein and iron. The AME predictions of nutrient intake functioned better across both countries in youth and adults than in infants, children, and the elderly.

While reasonably accurate in predicting nutrient intake, the AME approach is slightly less satisfactory in correctly classifying individuals as nutritionally adequate or inadequate (Table 5.2). In particular, the percent misclassified as adequate in calories and protein is outside the acceptable limit for infants and children in Bangladesh and is unacceptably high in protein (infants, children, youth) and iron (all groups) in Ethiopia. Though the overall percentage correctly classified as energy adequate did not reach 80% for infants and children in either country, it did reach or exceed 80% of the sample for all other demographic groups (except elderly males in Bangladesh). Aside from infants, "correct" classification levels were 80% or better for all



[1]The Bangladesh and Ethiopia data series are unadjusted for meal partakers
[2]Error of exclusion = energy inadequate by the self-reported measure but classified as adequate by the AME-predicted method; error of inclusion= energy adequate by the AME-predicted method but classified as inadequate by the AME-predicted method; correctly identified= AME-predicted method classifies according to the individually reported results.

Fig. 4b. Convergence in classification between individually reported and AME-predicted *iron* adequacy in Bangladesh, using energy-weighted AMEs.[1,2]

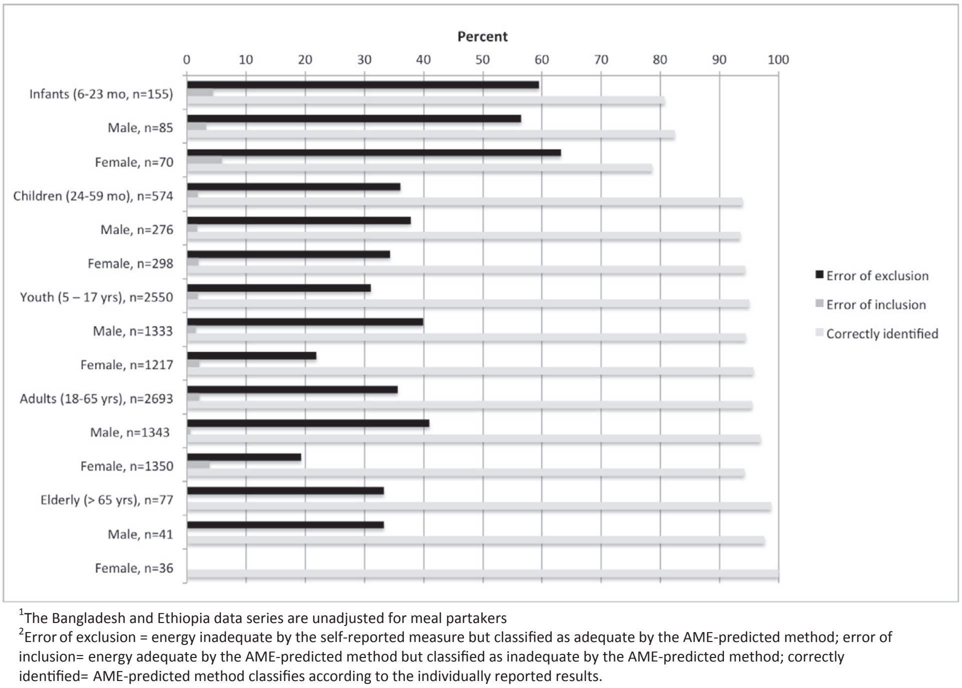


Fig. 4c. Convergence in classification between individually reported and AME-predicted *iron* adequacy in Ethiopia, using energy-weighted AMEs.[1,2]

Table 4
Percentage misclassified as adequate and inadequate using energy AME-predicted intake; by adjustment for meal partakers (Bangladesh).

Age-Sex Category	N of cases	Energy				Protein using energy AME				Iron using energy AME			
		Error of Exclusion[1] (%)		Error of Inclusion[2] (%)		Error of Exclusion (%)		Error of Inclusion (%)		Error of Exclusion (%)		Error of Inclusion (%)	
		Un-adj. [3]	**Adj.**	**Un-adj.**	**Adj.**	**Un-adj.**	**Adj.**	**Un-adj.**	**Adj.**	**Un-adj.**	**Adj.**	**Un-adj.**	**Adj.**
Infants (6-23 mo)	70	17.5	25.0	61.5	57.1	31.7	33.3	17.2	23.5	0.0	0.0	0.0	0.0
Male	33	17.2	32.1	75.0	60.0	42.1	50.0	21.4	29.4	0.0	0.0	0.0	0.0
Female	37	17.9	17.9	55.6	55.6	22.7	20.0	13.3	17.7	0.0	0.0	0.0	0.0
Children (24-59 mo)	166	13.1	15.8	42.4	38.5	29.1	27.1	15.3	14.4	1.3	1.3	73.3	66.7
Male	81	14.0	16.7	37.5	33.3	25.0	25.0	10.5	9.8	1.3	1.3	60.0	60.0
Female	85	12.0	14.9	45.7	42.1	32.3	28.6	20.4	19.3	1.3	1.3	80.0	70.0
Youth (5 – 17 yrs)	868	10.1	13.3	40.3	31.1	13.4	13.7	10.2	10.1	1.4	1.6	48.3	44.8
Male	454	12.2	15.6	41.9	29.1	16.8	16.8	8.8	8.2	1.9	2.1	35.7	32.1
Female	414	7.6	10.6	38.9	32.9	9.7	11.0	11.8	12.3	0.8	1.0	60.0	56.7
Adults (18-65 yrs)	1333	9.0	12.3	33.8	26.2	6.9	6.9	15.2	13.4	1.3	1.4	45.1	36.6
Male	664	6.1	9.3	36.8	27.9	5.3	5.0	18.5	16.2	1.5	1.7	39.1	29.7
Female	669	11.8	15.1	30.6	24.4	8.2	8.5	10.7	9.7	1.1	1.1	66.7	61.1
Elderly (> 65 yrs)	107	9.7	12.3	37.8	36.0	3.6	5.0	8.3	3.7	0.0	0.0	40.0	40.0
Male	61	13.8	20.0	40.6	38.9	6.8	7.3	11.8	5.0	0.0	0.0	50.0	50.0
Female	46	6.1	6.3	30.8	28.6	0.0	2.6	0.0	0.0	0.0	0.0	25.0	25.0

[1]Error of exclusion: the percentage classified as inadequate per individual report that is incorrectly classified as adequate by the AME-predicted method.
[2]Error of Inclusion: the percentage classified as adequate per individual report that is incorrectly classified as inadequate by the AME-predicted method.
[3]Unadj. = unadjusted for meal partakers; Adj. = adjusted for meal partakers.

demographic groups for protein (except female Bangladeshi children) and for iron in both countries.

4. Discussion

These analyses have yielded promising results for those wishing to use household-level food consumption data to predict individual-level intakes for most (though not all) demographic groups. The comparison of AME weighting approaches found that the energy-weighted AME consistently did at least as well or better at predicting individual intakes and adequacy than the AME associated with the particular nutrient being assessed. The energy AME-predicted intakes fell within ± 10 percentage points of the individually-reported intakes for the majority of the demographic groups across energy, protein, animal source protein, and iron, suggesting that the AME-based predictions performed reasonably well overall for this purpose.

However, the study results raise important concerns about using this approach for certain key vulnerable groups. The AME approach consistently overestimated infant intake of calories, protein, and iron compared with individually reported intakes, which was probably due

Table 5.1
Convergence of individually reported/AME-predicted nutrient intakes: Summary.[1–4]

	Energy		Protein		ASP		Iron	
	B[3]	E[4]	B	E	B	E	B	E
Infants (6-23 mo)	n	y*	n*	y	n	y*	n	y
Male	n	y*	n*	y*	n*	y*	n	y*
Female	y	y*	n*	y*	n	y*	n	y
Children (24-59 mo)	y	y	n*	y	n	y	y	y
Male	y	y	n*	y	n	y*	y	y
Female	y	y	n	y*	n	n*	y*	n*
Youth (5 – 17 yrs)	y	y	y	y	y	y	y	y
Male	y	y	y	y	y	y*	y	y
Female	y	y	y	y	y	y	y	y
Adults (18-65 yrs)	y	y	y	y	y	y	y	y
Male	y	y	y	y	y*	y	y	y
Female	y	y	y	y	n*	y	y	y
Elderly (> 65 yrs)	y	y	y	y*	y	n*	y*	y*
Male	y*	y*	y*	y	n*	n*	n*	y*
Female	y	y	y	y	y*	n*	y	y

[1] y = AME-predicted mean intake is within ± 10 pp. of individual report; n = AME-predicted mean intake is not within ± 10 pp. of individual report; * = AME-predicted mean intake may/may not be within ± 10 pp. once SEM is considered.
[2] All summary information in this table uses energy-weighted AMEs.
[3] B = Bangladesh.
[4] E = Ethiopia.

to the inability in these data to measure breast milk intake. In Bangladesh, the AME prediction also overestimated by about eight percentage points the iron intake of adult women, another important vulnerable group. In Bangladesh, among adults, the AME prediction of women's consumption of ASP was overestimated by over 11 pp. while the AME approach underestimated men's consumption by a margin of nearly ten pp., possibly reflecting the inequitable distribution of these preferred foods along gender-based lines.

The degree of accuracy of the AME-based method in predicting intakes was greater across all nutrients in the Ethiopia sample, suggesting that intra-household allocation of these nutrients in Ethiopia was generally more equitable than in Bangladesh, particularly when using energy AME weights. This result means that households in the Ethiopian sample appeared to allocate protein and iron equitably as a proportion of relative energy needs. However, the Ethiopia results showed less equitability when using the nutrient-specific AMEs, meaning that the intra-household allocation of iron and protein are much less equitable when considering relative iron and protein requirements.

These results suggest that applying the same blanket AME-based intake assumption to any household-level data set risks missing potentially useful information about differences between one country or

Table 5.2
Individually reported vs. AME-predicted *nutrient* adequacy: Summary.[1,2]

	Error of Exclusion is <10%						Total Classified Correctly as Inadequate is > 80%					
	Energy		Protein		Iron		Energy		Protein		Iron	
	B[1]	E[2]	B	E	B	E	B	E	B	E	B	E
Infants (6-23 mo)	n	y	n	n	y	n	n	n	n	n	y	n
Male	n	y	n	n	y	n	n	n	n	n	y	n
Female	n	y	n	n	y	n	n	n	n	y	y	n
Children (24-59 mo)	n	y	n	n	y	n	n	n	y	y	y	y
Male	n	y	n	n	y	n	n	y	y	y	y	y
Female	n	y	n	n	y	n	n	n	n	y	y	y
Youth (5 – 17 yrs)	y	y	n	n	y	n	y	y	y	y	y	y
Male	n	y	n	n	y	n	y	y	y	y	y	y
Female	y	y	y	y	y	n	y	y	y	y	y	y
Adults (18-65 yrs)	y	y	y	y	y	n	y	y	y	y	y	y
Male	y	y	y	y	y	n	y	y	y	y	y	y
Female	n	y	y	y	y	n	y	y	y	y	y	y
Elderly (> 65 yrs)	y	y	y	n	y	n	n	y	y	y	y	y
Male	n	y	y	y	y	n	n	y	y	y	y	y
Female	y	y	y	n	y	y	y	y	y	y	y	y

[1] B = Bangladesh.
[2] E = Ethiopia.

region and another in the patterns of distribution: predictions that are relatively accurate in one cultural context may be inaccurate in relevant ways in another, and may miss inequities in consumption among particularly vulnerable groups.

Because we did not have physical activity levels or proxy indicators of activity (e.g. occupations) for every individual in our sample to estimate individual-specific AMEs, we used the FAO/WHO human energy requirement estimates (2004), which assume moderate levels of energy expenditure, for all primary analyses. The sensitivity analysis to check whether AME predicted energy intakes were affected by assuming high PAL for youth and adults showed that changing the parameters made little difference in the accuracy of the predictions except in the case of adult males and, more substantially, children. For both of these groups, in Bangladesh and Ethiopia, using AMEs constructed with moderate PAL assumptions to predict energy intakes produced better alignment with individually reported intakes than using high PAL assumptions. These findings do not tell us anything about actual activity levels, but they do illustrate that intra-household distribution conformed to a pattern that would be expected if youth and adults had moderate, not high, PAL.

Using AMEs based on information about individuals' actual activity levels could yield different results than those presented in this paper, and the sensitivity of the results to different sets of nutrient requirements should be evaluated where possible. This point has been argued in the intra-household distribution literature (Haddad and Kanbur, 1992; Bouis and Pena, 1997), and in the Philippines; when energy expenditure was factored into the definition of 'fair share', male-biased inequities were smaller (Haddad et al., 1995b). With that said, many national statistics offices using HCES data to predict individual intakes are likely to rely on the FAO AME estimates assuming moderate PAL for lack of individual-level activity level information for their populations. Our sensitivity analyses for Bangladesh and Ethiopia suggested this is a reasonable approach.

Correctly identifying groups at risk of inadequate consumption is an important goal of analyzing food consumption data. Errors of exclusion exceeded 10% for several subgroups in both Bangladesh and Ethiopia. The accuracy of the predictions is affected, in part, by the prevalence of inadequate consumption in a particular age/sex group or in the population as a whole. In Bangladesh, for example, where inadequate iron consumption is extremely widespread, the issue of committing errors of exclusion loses relevance: it is safe to treat the entire population as inadequate and design policies and programs accordingly. In any case, the tolerable degree of misclassification is a matter of judgment, but one risk of systematically overestimating nutrient adequacy in a particular age/sex group is that an important nutritional issue may be underemphasized in food policy debates and in the design of policies and programs to address nutrition concerns.

Most household-level consumption information is collected with the implicit assumption that this household food supply is shared (usually according to the energy AME assumption) among members of the household, without considering some individuals' absence from meals, or the presence of guests. But failing to take account of the number of individuals actually consuming the food can result in both error and systematic bias. (For example, if wealthier households are more likely to have guests, AME predictions of consumption would overestimate amounts actually consumed, and thus find a higher degree of inequality in consumption between richer and poorer households than is actually the case). In this particular Bangladesh data set, however, adjusting for the presence or absence of household members at particular meals did not improve the accuracy of intake predictions, although the data did not permit any assessment of food that might have been consumed outside the home by the absent members.

The study reported here had some unavoidable limitations. Intake data were derived from a single 24-recall from each household, which may not have been representative of each household's or individual's usual intake. Use of a single 24 h recall is, however, appropriate for doing analysis of aggregated information, as unusually high and low estimates should be about equally represented in the sample overall. Intakes of individuals within the household were derived from the food preparer's report of each household member present for each meal. There may be some normative bias in the preparer's report, and her estimate of quantities consumed may also contain a degree of recall error. Further, although it was possible to adjust estimates of available food in the household for members' absence from a particular meal (Bangladesh only), there was no information on food that may have been consumed outside the home by those absent members. In addition, neither the reported intakes nor the AME-predicted intakes accounted for the energy or protein contributions of breast milk. We would expect infant energy and protein intake to be underestimated in the respondent-reported method and overestimated in the AME-predicted method at least in part for this reason. The small sample size of infants and elderly across most nutrient analyses may also have affected the robustness of these results.

As mentioned earlier, illustrative estimates of errors of exclusion and inclusion in predicting apparent nutrient adequacy are based on whether an individual's intake reaches the estimated average requirement (for energy and protein) or is classified as being at risk of inadequacy (for iron) even though the EAR is derived from population data (based on probability in the case of iron) and not intended as a diagnostic criterion. To illustrate the significance of a divergence in intakes between AME-predicted and individual report, the implicit assumption in this analysis is that failure to meet the EAR accurately reflects the risk or probability of inadequate consumption at the individual level.

The household level data used in this analysis were based on a 24-h recall of consumption in the household. The strength of these data sets is that there is comparable information at the household and individual levels that enabled us to isolate the "AME effect" from any other factors that could cause divergent estimates between individually reported 24-h recalls and household consumption and expenditure data. But the question remains whether the results would hold if information on individual intake were compared with household level consumption imputed from expenditure data of the kind collected in HCES. Finally, the data set from Ethiopia was collected in 2014, but the Bangladesh data set is from 2003, and it is possible that intra-household food distribution patterns have changed since that time. However, the purpose of this analysis is to assess consistency between AME-predicted intake and directly reported data, not to determine the current dietary situation in each country, so the recency of the data would not affect the results of greatest interest to this study. The most recent HCES in Bangladesh used the same unique format for collecting consumption data, opening the possibility for further comparative analysis (Sununtnasuk and Fiedler, this issue).

While the AME-based method is a common approach for deriving individual intakes from household level data, there have been efforts to apply econometric modeling approaches to meet this purpose (Naska et al., 2001a, 2001b; Vasdekis et al., 2001; Vasdekis and Trichopoulou, 2000), for instance, to identify specific foods or food categories that are disproportionately consumed by a particular demographic group. For example, Naska et al. (2001b) used non-parametric modeling to 'individualize' HCES data from Belgium, Greece, Norway, and the United Kingdom and found correlations between the 'individualized' HCES consumption estimates and the individual dietary intake estimates were 'good', or 'very good' for all food groups except fish/seafood, ranging from r = 0.44 (nuts) to r = 0.96 for milk and milk products. Such models could also assess the degree to which socio-economic status and other household or individual-level factors affect the accuracy of AME-based predictions so that they may be adjusted for different types of households. Preliminary additional analyses of the Bangladesh data reported in this study have suggested that household energy distribution is less equitable among households that are more food insecure (Kang, Coates, and Houser 2006, unpublished), however much more remains to be understood about how this phenomenon could affect the application of energy AMEs for estimating intakes, both in Bangladesh and elsewhere.

5. Conclusion

This study showed that the AME-based approach to estimating intakes worked well across several nutrients and most demographic groups, but it found that the method is not as useful for key nutritionally vulnerable groups such as women of child-bearing age, infants under age two, and children in certain contexts. Measuring dietary diversity of women and young children as part of an HCES could help fill in some of these blanks for relatively low time-cost, though the qualitative results could not be used to quantify nutrient intakes or nutrient adequacy. Therefore, in addition to investing in improving HCES, countries should make parallel investments in their institutional capacity to collect, analyze, and use individual dietary data for agriculture, health and nutrition-related decision-making about important demographic groups. Furthermore, integrating individual diet recalls into HCES can add valuable complementary information that would not otherwise be available, while also permitting further validation of these indirect approaches (econometric modeling, AME-based prediction). There have been few opportunities to match household with individual level data, and more would contribute to understanding the limitations and the potential of these methods for different food and nutrition policy uses.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodpol.2017.08.010.

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