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Novel Strategies for Measuring Complementary Feeding and Achieving Behavior Change in East Africa

By
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Doctor of Philosophy

Nutrition and Health Sciences

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Novel Strategies for Measuring Complementary Feeding and Achieving Behavior Change in East Africa

By

Emily Faerber
B.S., Western Washington University, 2008
M.P.H., University of Washington, 2012

Advisor: Amy Webb Girard, Ph.D.

An abstract of
A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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2019

ABSTRACT

Novel Strategies for Measuring Complementary Feeding and Achieving Behavior Change in East Africa

By Emily Christine Faerber

Objective. Growth failure rapidly accumulates during the period of complementary feeding, from 6 to 23.9 months. Identifying strategies to ensure appropriate complementary feeding requires appropriate measurement methods. Current methods, including infant and young child feeding indicators that are amenable to large surveys, are lacking in scope and largely fail to assess the more complex interrelationships between complementary feeding practices. The goal of this dissertation was to describe novel methods for measuring complementary feeding practices and to evaluate impact pathways of a nutrition-sensitive agriculture project on complementary feeding outcomes.

Methods. We use data from two countries in East Africa. We computed correlation coefficients to assess the relative validity of indicators of portion size and complementary food consistency in a sample of children 6 to 13 months in southern Ethiopia. We used exploratory factor analysis and exploratory structural equation modeling to identify patterns and predictors of complementary feeding practices in rural Malawi. Lastly, we used mediation analysis to assess potential impact pathways of a nutrition-sensitive agriculture project on complementary feeding outcomes in southern Ethiopia.

Results. In Aim 1, we found that the indicator of portion size was significantly correlated with energy intake from and quantity of complementary foods consumed. The indicator of complementary food consistency was weakly but significantly correlated with energy density. Combining indicators of portion size and feeding frequency was more predictive of low complementary food energy intake than feeding frequency alone. In Aim 2, we found that complementary feeding indicators are correlated and that two-factor solutions fit the data well. Indicators of food access and availability were associated with complementary feeding. In Aim 3, we found that nutrition knowledge and food security mediate modest impacts of a nutrition-sensitive agriculture project in southern Ethiopia, but the strongest impact was seen among households receiving tangible child feeding tools, and was not explained by either mediator.

Conclusion. Survey-based indicators can measure multiple dimensions of complementary feeding practices for use in epidemiological research. Drivers of complementary feeding practices include environmental and individual-level factors. Providing caregivers with tools to promote complementary feeding enhances the impact of a nutrition-sensitive agriculture project.

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Acronyms

AUC	Area under the (ROC) curve
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CFI	Complementary Feeding Index
CIP	International Potato Center
COM-B	Capability, Opportunity, Motivation-Behavior (framework)
CWW	Concern Worldwide
DHS	Demographic and Health Survey
DRI	Dietary Reference Intake
EAR	Estimated Average Requirement
EFA	Exploratory Factor Analysis
ESEM	Exploratory Structural Equation Modeling
FAO	Food and Agriculture Organization
FIES	Food Insecurity Experience Scale
g	Gram
HAZ	Height-for-age z score
HBT	Healthy Baby Toolkit
HLC	Healthy Living Club
ICC	Intraclass Correlation Coefficient
IDECG	International Dietary Energy Consultative Group
IFU	International Food Unit
IQR	Interquartile Range
IYCF	Infant and Young Child Feeding
KAP	Knowledge, Attitudes, Practice
kcal	Kilocalorie
kg	Kilogram
KMO-MSA	Kaiser-Meyer-Olkin Measure of Sampling Adequacy
LAZ	Length-for-age z score
LMIC	Low- and middle-income countries
MAD	Minimum Acceptable Diet
mcg	Microgram
MDD	Minimum Dietary Diversity
mL	Milliliter
MMF	Minimum Meal Frequency
OFSP	Orange-fleshed Sweet Potato
PAHO	Pan American Health Organization
PIN	People in Need
PSEA	Portion Size Estimation Aids

QDBH	Quality Diets for Better Health (project)
RAE	Retinol Activity Equivalents
RDA	Recommended Dietary Allowance
rFIES	Reverse-coded Food Insecurity Experience Scale
RMSEA	Root Mean Square Error of Approximation
ROC	Receiver Operating Characteristic
SAM	Severe Acute Malnutrition
SARI	Southern Agriculture Research Institute
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SRMR	Standardized Root Meat Square Residual
SSA	Sub-Saharan Africa
TA	Traditional Authority
TLI	Tucker Lewis Index
UNU	United Nations University
WHO	World Health Organization
WLSMV	Weighted Least Square Mean and Variance Adjusted

Chapter 1 - Introduction

The prevalence of child undernutrition has been in decline for several decades, but the improvement has been slow in sub-Saharan Africa (SSA). Rapid population growth in this region means the crude number of undernourished children is actually increasing [1], and childhood undernutrition remains the greatest contributor to disability-adjusted life-years [2]. Stunting, defined as length- or height-for-age z scores (LAZ/HAZ) more than two standard deviations below the median of the World Health Organization (WHO) Child Growth Standards [3, 4], is the most prevalent anthropometric form of child undernutrition. Stunting rates are highest in East Africa, in particular [1]. Early life growth failure puts children at acute risk of death [1], but deleterious effects can be longer lasting as well. A child who is stunted at his or her second birthday is on a life course trajectory in which he or she can expect to have shorter adult stature [5], reach lower levels of schooling with subsequently lower economic productivity in adulthood [6, 7], and experience greater risk of poor birth outcomes [5, 8] than his or her non-stunted counterparts.

While some degree of stunting may be present among neonates, particularly in low- and middle-income countries (LMIC), as a result of deficits in utero, population average LAZ begins to decrease rapidly at 3 to 6 months of age, a trend that continues before stabilizing near the second year of life [9]. In SSA, for example, length-for-age is already nearly one-half of a standard deviation below the median among infants in their first month, and yet this region sees the sharpest drop of any other at a pace averaging -0.1 standard deviations per month from 3 to 24 months of age [9].

What might account for such marked growth failure? Unlike other forms of malnutrition that may develop acutely, stunting is indicative of chronic nutrient inadequacy, and has multiple etiologies that can include inadequate nutrient intake, inadequate nutrient absorption, conditions such as infection that increase nutrient demands, or a combination of each [10]. To allow for tissue deposition required for normal growth, energy needs per kilogram body weight are higher in infancy than at any other age or life stage, then slowly decline through early childhood, adolescence, and adulthood [11]. Infants and young children, particularly those in LMIC, may be exposed to pathogens by way of unimproved water and sanitation facilities, proximity of animals and animal feces, and through hand-to-mouth behaviors. Together, these pathogen exposure pathways can lead to environmental enteropathy and may contribute to nutrient inadequacy and subsequent growth failure [12-15].

The rapid accrual and lasting impact of stunting in the first thousand days have garnered much attention and investment from research, governmental, and non-governmental organizations alike, with the goal of preventing stunting and its negative effects. The WHO conceptual framework on *Childhood Stunting: Context, Causes, and Consequences* illustrates that inadequate complementary feeding is a central cause of stunted growth and development [16]. Further, complementary feeding is a complex behavior, impacted by several underlying factors that may include food access and security, feeding environment, caregiver knowledge and resources (both time and financial resources), and maternal factors [16].

Given the importance of complementary feeding, measurement methods are critical for assessing population practices, identifying vulnerable groups, evaluating interventions, and conducting sound research on determinants and outcomes of appropriate or inappropriate complementary feeding [17, 18]. Yet researchers and public health professionals must often choose between sample size and statistical power, or rigorous, gold-standard assessment methods. There are serious limitations in complementary feeding assessment methods, and the time calls for novel approaches for understanding complementary feeding.

1.1 Research Aims

This dissertation aims to enhance understanding of complementary feeding and its place in the broader framework using data from Ethiopia and Malawi. The specific aims are:

Specific Aim 1: Validate novel indicators of portion size and complementary food consistency in a sample of infants 6 to 13.9 months old in southern Ethiopia.

- Sub-aim 1.1: Assess the correlation between a survey-administered indicator of portion size and energy and food intake as determined by multiple-pass 24-hour recall in a sample of infants 6 to 13.9 months in southern Ethiopia.
- Sub-aim 1.2: Assess the correlation between a survey-administered indicator of complementary food thickness and average energy density of complementary foods as determined by multiple-pass 24-hour recall in a sample of infants 6 to 13.9 months in southern Ethiopia.
- Sub-aim 1.3: Assess whether survey-administered indicators can accurately identify children from a sample of infants 6 to 13.9 months in southern Ethiopia with low complementary food energy intake.

Specific Aim 2: Identify patterns of complementary feeding practices in a sample of infants and young children ages 6 to 17.9 months in rural, central Malawi.

  - Sub-aim 2.1: Conduct exploratory factor analysis on indicators of complementary feeding to identify the factor structure of latent complementary feeding factors.

- Sub-aim 2.2: Examine the associations between latent complementary feeding factors and potential predictors of complementary feeding using exploratory structural equation modeling.

Specific Aim 3: Assess the effect of a nutrition-sensitive, orange-fleshed sweet potato promotion project on complementary feeding outcomes and explore potential impact pathways.

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Chapter 2 - Background

Complementary feeding is the giving of foods and liquids in addition to breastmilk or breastmilk substitutes. Beginning at approximately 6 months of age, breastmilk alone can no longer provide sufficient nutrients for growing, developing infants, necessitating the introduction of complementary foods.

2.1 Evolution of Estimated Energy Requirements of Infants and Young Children

Nutrition scientists have historically agreed that a key first step in developing recommendations for feeding infants and young children has been the estimation of total energy requirements in this age range [1].

The first attempt to estimate energy needs throughout the lifecycle came in 1949, when the Food and Agriculture Organization of the United Nations (FAO) convened a group of experts for its first meeting, of what would become several [2]. The topic was revisited by FAO in 1956, jointly with the World Health Organization (WHO) in 1971 [3], and with both WHO and United Nations University (UNU) in 1981 [4]. For most ages and life stages, the FAO/WHO/UNU Expert Consultation estimated energy requirements by first estimating basal metabolic rates and then adjusting based on physical activity, but this approach was considered particularly problematic in infants and young children [4]. While reasonable estimates of infants' basal metabolic rates were available at the time, the Consultation deemed it inappropriate to make assumptions about energy expenditure from physical activity or growth in this age group. Instead, energy needs were estimated by observed energy intakes of healthy children with appropriate growth in developed countries. Estimated energy intakes from breastmilk were approximated either by feeding infants breastmilk with a bottle, or using test weighing, in which infants are weighed before and after breastfeeding. The resulting estimates for total energy needs from both complementary foods and breastmilk was increased by 5% based on evidence that test weighing underestimates actual breastmilk intakes [4].

In 1986, the International Dietary Energy Consultative Group (IDECG) was formed, and adopted a mandate that included "re-examining the energy requirements of infants and children from the point of view of physical activity and energy expenditure" [5]. In 1994, the IDECG reviewed updated evidence, including estimates of total energy expenditure using doubly labeled water and observational studies to estimate energy demanded of normal growth [6, 7]. They concluded that the energy requirements of infants and young children reported by the 1981 FAO/WHO/UNU Expert Consultation were too high. The group produced a set of updated estimates, which were up to 39% lower than those resulting from the 1981 FAO/WHO/UNU Expert Consultation [8].

A WHO report titled *Complementary Feeding of Young Children in Developing Countries: a review of current scientific knowledge* was published in 1998; this report was the first to focus solely on the nutrient needs of children under 2 years in low- and middle-income countries (LMIC), and to translate estimated nutrient needs into recommended complementary feeding practices [1]. The 1998 WHO report agreed that estimated energy needs from the FAO/WHO/UNU Expert Consultation in 1981 likely overestimated the energy needs of children under 2 years. Authors of the 1998 WHO report argued that estimating energy needs by dietary intake was more problematic than estimating energy expenditure and energy cost of growth, and thus relied on the same literature used by the IDECG for total energy needs of infants and young children. They further reviewed literature to estimate breastmilk intake, energy density of breastmilk, and breastmilk energy intake for both developing and industrialized countries [1].

These estimates were used to calculate energy needs from complementary foods in particular; they also considered how estimated complementary food energy needs would change assuming low (less than 2 standard deviations below the mean) or high (greater than 2 standard deviations above the mean) breastmilk energy intake [1].

In 2003, Dewey and Brown published an update to the 1998 WHO report [9]. In the update, they explained that a new consensus among the FAO/WHO/UNU Expert Consultation had been reached to base recommended energy intakes for infants and young children on a study by Butte *et al.* [9, 10]. Butte *et al.* assessed total energy expenditures using doubly labeled water in a longitudinal cohort of 76 infants in Houston, Texas (55 of whom were white, 7 African American, 11 Hispanic, and 3 Asian American) [10]. From these estimates, Dewey and Brown subtracted existing estimates of average breastmilk energy intake in the first two years of life in developing countries, to yield updated estimates for complementary food energy needs in developing countries [9]. Final estimates of total energy requirements, breastmilk energy intake, and complementary food energy requirements are summarized in Table 2-1; these estimates include high estimates of total energy requirements, as well as complementary food energy requirements for infants assumed to have low, average, and high breastmilk energy intake.

2.2 Recommendations for Achieving Complementary Food Energy Intake

Two types of studies can be undertaken to explore the relationships between complementary feeding practices and complementary food energy intake: experimental studies in which fixed feeding protocols are followed in a controlled environment, or observational studies that measure energy intake and observe feeding practices in child-caregiver dyads in their typical feeding environment [1]. Experimental feeding studies offer greater control of potential confounders and feeding practices not being studied, but for the same reason are unlikely to provide accurate information about feeding practices in natural conditions [1]. In observational studies, on the other hand, “the number of meals offered, the timing of meals, and types and preparation of foods are not deliberately controlled…the enormous number of variables makes the statistical modelling extremely complex” [1].

A third option relies on “theoretical calculations” to identify the combination of feeding frequency, energy density, and amount of food consumed that would meet recommended complementary food energy intake for infants and young children [1, 9]. This method was employed for the 1998 WHO report [1], and subsequently by Dewey and Brown in 2003 [9]. A number of assumptions are made in the process, starting with which values to use for energy requirements that were discussed in the previous section. Dewey and Brown used high estimates of total energy required (mean plus two standard deviations) that would meet the needs of 97.5% of young children; they also assumed average breastmilk energy intake [9].

In 2003, the Pan American Health Organization (PAHO)/WHO published ten *Guiding Principles for Complementary Feeding of the Breastfed Child* (henceforth referred to as the Guiding Principles), which were largely based on the estimates and recommendations published by Dewey and Brown in the same year [11]. The Guiding Principles encompass several different domains of complementary feeding (Box 2-1). These include continued breastfeeding, both quantity and quality of complementary foods, responsive feeding in which caregivers respond to cues from the child about his or her needs and capabilities, hygienic food preparation and storage, and the use of supplementary products to fill gaps in child diets [11]. Recommendations for energy density and feeding frequency, in particular, are based primarily on calculations for achieving average recommended complementary food energy intake plus 2 standard deviations, as outlined by Dewey and Brown in 2003 [9].

The guidelines are tailored to the needs of healthy, breastfed children, including children from LMIC. Children with any acute or chronic illness, who are malnourished, or those who are not breastfed, may have unique nutrient needs. However, the Guiding Principles are appropriate for implementing policies and programs intended to promote optimal nutrition in early life [11]. For the purpose of this dissertation, the guiding principles related to energy intake are discussed in detail below.

2.2.1 Gastric Capacity and Portion Size Assumptions

The volume of the average adult stomach is 50 milliliters (mL) when empty, and folds called rugae, are visible on the interior of the stomach [12, 13]. When foods and liquids are swallowed, they pass through the esophagus and enter the stomach, typically in less than 10 seconds, and the rugae flatten and disappear as the stomach expands to hold volumes of 1000 mL or more [12, 13]. Neonates' stomachs, however, can hold only an estimated 10 to 35 mL [14], though growth is rapid in the first days and weeks of life [15]. It has been estimated that a child's gastric capacity reaches 200 mL [16] to 360 mL by his or her first birthday, and up to 500 mL by the second [17], though the evidence basis for these estimates is not clear.

Sanchez-Grinan *et al.* conducted an experimental study to assess the impact of dietary energy density on energy intake in nine children aged 7 to 16 months who were recovering from severe acute malnutrition (SAM); they found that the children consumed 34 to 49 grams per kilogram body weight per meal (g/kg/meal) of a high energy density puree, and 40 to 66 g/kg/meal of a low energy density puree [18]. The WHO cited these findings in their 1998 report, and assumed a functional gastric capacity of 30 to 40 g/kg/meal for infants and young children [1]. In developing their recommendations, Dewey and Brown and the Guiding Principles assume a functional gastric capacity of 30 g/kg/meal, or 249 g/meal, 285 g/meal, and 345 g/meal for children 6 to 8.9 months, 9 to 11.9 months, and 12 to 23.9 months, respectively [9, 11]. Subsequent calculations to estimate required energy densities and feeding frequencies per day then, assume that children are fed and consume up to these estimates. Of note, the reference body weights for each age range can be computed as 8.3 kg for infants 6 to 8.9 months, 9.5 kg for infants 9 to 11.9 months, and 11.5 kg for children 12 to 23.9 months.

Portion size recommendations have generally been avoided. Rather, the Guiding Principles call for practicing responsive feeding, citing the need "not to be overly prescriptive about the amount of complementary foods to be consumed…each child's needs will vary due to differences in breast milk intake and variability in growth rate" [11].

2.2.2 Feeding Frequency and Energy Density Recommendations

Combinations of feeding frequency and complementary food energy density were then calculated to meet complementary food energy requirements for 97.5% of a theoretical population of infants and young children, based on the above recommendations of gastric capacity and assuming average breastmilk energy intake (Table 2-2). The Guiding Principles recommend an energy density of 0.8 kilocalories per gram (kcal/g) or higher. In addition to 1 to 2 snacks per day, it is recommended that infants 6 to 8.9 months receive 2 to 3 meals per day, and children 9 months and older receive 3 to 4 meals per day [11].

2.2.3 Complementary Food Consistency Recommendations

Complementary food consistency is sometimes used as a proxy for energy density, and is particularly relevant to this dissertation. Complementary foods around the world, but particularly in LMIC, are often boiled/heated gruels or porridges prepared from starchy staples such as wheat, maize, potato, sweet potato, or rice [19, 20]. When starch is heated in water, its structure is modified such that it undergoes the process of gelatinization, referring to the swelling of starch as it takes on water, resulting in increased viscosity [20, 21]. As more of the starchy ingredient is added to a recipe, the energy density increases, but so too does its viscosity. This relationship has been demonstrated with porridges prepared under standardized conditions with flours commonly available in 15 African countries and in Vietnam [22]. Thus, viscosity, or consistency, is a relevant trait of complementary foods with respect to energy density.

Consistency is a less quantifiable characteristic of complementary foods than is energy density, and so recommendations around consistency are descriptive in nature. The Guiding Principles recommend "gradually increase[ing] food consistency…as the child gets older, adapting to the infant's requirements and abilities" [11]. The guidelines use adjectives like "pureed" "mashed" and "semi-solid" for appropriate complementary foods at 6 months, "finger foods" at 8 months, and "family" foods by 12 months [11].

2.2.4 Other Guiding Principles

The complementary feeding recommendations discussed thus far have centered around meeting complementary food energy intake. There are, however, several guiding principles related to other aspects of complementary feeding. The first two guiding principles pertain to exclusive breastfeeding for the first six months of life, followed by continued breastfeeding to at least 2 years while complementary foods are given [11].

Another recommendation in the Guiding Principles is that infants and young children should be offered a variety of complementary foods. Specifically, it is recommended that young child diets include animal-source protein daily, or include supplements or fortified products to provide nutrients otherwise found in animal-source foods [11]. The Guiding Principles also call for the daily feeding of vitamin A-rich fruits and vegetables, and foods with enough fat [11].

2.3 Complementary Feeding and Nutrition Outcomes

2.3.1 Portion Sizes, Total Energy Intake, and Nutrition Outcomes

Faber *et al*. used 24-hour recall in infants 4 to 24 months old in rural South Africa to look specifically at intake of infant cereal. They found that the children consumed infant cereal "on average approximately a quarter of the recommended portion size" (though it is not clear what portion size was considered recommended) and that infant cereal contributed only minimally to overall energy intake [23]. Kimmons *et al*. found that infants in Bangladesh tended to receive recommended meal frequency and energy density of complementary foods, but median complementary food intakes were considerably lower than the 30 g/kg/meal assumption made in the Guiding Principles [24]. In fact, where assumed intakes are 249 g and 285 g for infants 6 to 8.9 months and 9 to 11.9 months [11], Kimmons *et al.* observed intakes of only 73 g and 117 g, respectively. The authors also found that infants were getting insufficient energy from complementary foods overall [24]. Kulwa *et al.*, on the other hand, found that a range of inadequate complementary feeding practices – including infrequent meals, low energy dense foods, and small portion sizes as determined by multiple-pass 24-hour recall – all contributed to low energy intake from complementary foods in Tanzania [25].

2.3.2 Complementary Foods Energy Density, Total Energy Intake, and Nutrition Outcomes

In the general population, energy density of foods is associated with overall energy intake [26]. In 1977, Fomon *et al*. were one of the first to explore this relationship specifically in infants [27]. Between the ages of 112 and 167 days, 88 infants were given one of two formulas and their intakes were assessed; one formula was a commercial infant formula with an energy density of 0.67 kcal/g, the other was fortified skim milk and had an energy density of 0.36 kcal/g, which is nearly half that of the formula. Though infants consumed greater quantities (in grams) of the less energy dense formula, their overall energy intakes were lower [27]. So, while the infants receiving the less energy dense formula at least somewhat regulated their intake to consume a greater volume, their energy intakes were still lower than their counterparts receiving the more energy dense formula.

Sanchez-Grinan *et al*. were among the first to explore energy density and overall intake in infants with complementary foods [18]. Nine children ages 7 to 16 months who were hospitalized and recovering from SAM in Lima, Peru were fed a puree with an energy density of either 1.0 kcal/g or 0.5 kcal/g; the purees had added cornstarch to achieve similar texture. They found that infants had higher energy intake when fed the 1.0 kcal/g diet despite consuming greater quantities (in grams) of the 0.5 kcal/g puree [18]. In a similar study, Brown *et al*. alternated a sequence of diets ranging from 0.4 kcal/g to 1.5 kcal/g between three to five times per day in 18 children ages 6 to 18 months who were hospitalized and recovering from SAM in Peru [28]. The children, all of whom were fully weaned, were fed by trained nursing aides; the amounts consumed per feeding episode were not prescribed. Less energy-dense foods were mixed with thickening agents, while more energy dense foods were mixed with amylase to prevent thickening such that all foods were of comparable consistency. The authors found that at lower energy densities, children consumed more food, but still achieved lower overall daily energy intake; similar results were observed for feeding frequency being associated with overall energy intake [28]. While neither the sample nor the feeding conditions of either study are generalizable, the results indicate that even though children may, to some extent, regulate their food intakes based on energy density, they cannot fully compensate for low energy dense foods. Similar associations between energy density of complementary foods and overall energy intake have been reported in a sample of healthy children in Spain, a high-income country [29].

Little is known about the relationship between energy density of complementary foods and growth outcomes in observational studies. However Kikafunda *et al.* did find that infants and young children fed less energy dense foods had higher rates of stunting in Uganda [30].

2.3.3 Complementary Food Consistency, Total Energy Intake, and Nutrition Outcomes

The giving of thin consistency complementary foods has been negatively associated with nutritional status in India [31, 32] and China [33]. Teshome *et al* found that infants in northern Ethiopia whose first weaning food was a thin porridge had higher odds of stunting than children who first received cow's milk [34].

Amylase is an enzyme that hydrolyzes starch [12]. The addition of amylase to porridges has been tested in several LMIC, and has been shown to allow for increased energy density at still-socially acceptable viscosities [35-40]. However, the impact of amylase added to complementary foods on growth outcomes has been inconsistent [41-44].

Even if an appropriate energy density could be achieved in thin porridges, complementary food consistency is not only important for its relationship to energy density and energy intake. The giving of complementary foods of increasingly solid consistency, and advancing to textured foods, are important complementary feeding practices in their own right. Animal studies show altered facial and dental anatomy and physiology on soft diets alone [45]. Furthermore, increasingly solid and textured foods stimulate the nervous system to prompt neurodevelopment in mice, and "catch-up" development may not be possible when textured foods are introduced at later ages [46]. Lastly, delayed exposure to foods at an early age is associated with rejection of or sensitivity to such foods later in life [45].

2.4 Comment on Complementary Feeding Recommendations

As described above, the process of developing complementary feeding recommendations began with the task of estimating total energy needs from complementary foods, which requires knowledge not only of total energy needs for infants and young children 6 to 23.9 months, but also of breastmilk energy intakes in this age range. “Estimates…are derived from measurements on individuals” [4], where a mean is computed and around which a confidence interval lies. The challenge is in translating estimates and confidence intervals describing individual variation within a population to recommendations intended for the population at large.

In the United States, the Food and Nutrition Board (FNB) of the Institute of Medicine (IOM) is tasked with developing recommendations for nutrient intakes for the American people, commonly known as the Dietary Reference Intakes (DRIs). The DRIs are, in fact, comprised of several values, including [16, 47]:

- Estimated Average Requirements (EAR), which are median recommended nutrient intakes for meeting the needs of half of healthy individuals in a population.
- Recommended Dietary Allowance (RDA), which are recommended nutrient intakes for meeting the needs of 97.5% of healthy individuals in a population.
- Adequate Intakes, which are recommended nutrient intakes based on observational and experimental data when insufficient evidence exists to estimate an EAR and/or RDA.
- Tolerable Upper Intake Levels are maximum nutrient intakes that are not believed to cause harm in 97.5% of healthy individuals in a population.
- Acceptable Macronutrient Distribution Ranges are recommended macronutrient intakes expressed as a percentage of overall energy intake.

Dietary Reference Intakes exist for micronutrients, macronutrients, and total water. There is one notable exception for which there is no DRI: energy. Energy is unique, in that excess energy intake could result in excess weight gain [16]. An estimated energy requirement that meets the needs of half of a normally distributed population also *exceeds* energy requirements for almost all of those same individuals.

The appropriateness of using of high estimates of energy needs to meet – or exceed – the needs of 97.5% of the population for developing recommendations directly related to energy intake could reasonably be debated. What are potential downsides of basing complementary feeding recommendations on estimates of energy intake that, assuming a normally distributed population, would overestimate energy needs for a majority of the population?

The emphasis on malnutrition in LMIC has generally focused on preventing and treating undernutrition. However, the prevalence of overweight and obesity is increasing globally, as is the burden of diseases associated with excess body weight [48]. The so-called double burden of malnutrition – the existence of both under- and overweight in the same countries, communities, and households – has garnered increased attention from the international nutrition community in recent years [49, 50]. Thus, any potential preference to err on the side of excess calories is likely waning. Preventing and treating undernutrition is an important goal, but should not come at the expense of promoting excess intake. This is a particularly relevant concern given shifts in diet and physical activity, known as the nutrition transition. The nutrition transition is marked by simultaneous decreases in fiber and whole grain consumption, and increases in physical inactivity and consumption of energy dense foods that are high in saturated fat, sugar, and refined carbohydrates [51-53]. Potential drivers of the nutrition transition include urbanization, economic growth, globalization, and the emergence of technology that promotes physical inactivity [54, 55]. The nutrition transition is most well-characterized in Latin America, Asia, and North Africa, but trends are also emerging in sub-Saharan Africa, particularly in urban areas [56].

There is some literature to support the idea that infants and young children will regulate their intake depending on the energy density of complementary food, but that they may be unable to overcome very low energy dense foods given limitations on gastric capacity [18, 27, 28]. Thus, one could argue that it is prudent to base recommendations for energy density and feeding frequency on more conservative estimates. The Guiding Principles withhold making specific recommendations regarding portion size per se; rather, they rely on assumptions about gastric capacity for developing energy density and feeding frequency recommendations, and urge the practice of responsive feeding [11].

Its importance notwithstanding, responsive feeding practices are challenging to impart. Thus, while relying on responsive feeding to promote optimal intake is theoretically sound, the difficult question becomes whether it is sufficient in practice. Or, would portion size guidelines as a complement to responsive feeding be useful? Is an undernourished and/or chronically underfed child likely to provide sufficient hunger cues? What about a child recovering from acute illness? Might underlying food insecurity influence a caregiver's interpretation of hunger and fullness cues, or might she be less likely to actively encourage continued eating? In these instances, portion size guidelines may prove useful.

However, once portion size recommendations are communicated, the reality is that caregivers following all recommendations are most likely overfeeding. If one relies on the assumption that a caregiver who is practicing responsive feeding recognizes a child who is over-consuming, it is important to consider how that caregiver, particularly from a food insecure household, might react to a child not finishing his or her portion. Caregivers may feel tempted to force feed, or to unsafely store leftover complementary food for later feeding. Portion size recommendations should always accompany education around principles of responsive feeding and food safety in order to address these potential risks.

Lastly, the energy recommendations discussed in this chapter are for healthy, normal weight children. However, given the prevalence of undernutrition, infectious disease, and poor water and sanitation, these population-level recommendations may be too high or too low for average infants and young children in LMIC. Important knowledge gaps exist around actual energy needs of infants and young children in LMIC, and around the role of complementary feeding recommendations in meeting or failing to meet such needs.

2.5 Dietary Assessment in Infants and Young Children

Dietary assessment is fraught with opportunities for error, which can come in the form of random error or systematic error [57]. Sources of systematic error can include social desirability bias, recall bias, and interviewer bias [58]. Methods that tend to reduce the opportunity for error are often more resource-demanding [57]. Concerns about error and/or bias are relevant for dietary assessment in any population and in any context. Yet, assessing the diets of infants and young children, particularly in LMIC, carries several additional, unique challenges.

Breastfeeding is recommended exclusively in the first 6 months of life, and when complementary foods are added thereafter until at least two years. And while breastfeeding practices are suboptimal around the world, breastfeeding is common in LMIC. Assessing exactly how much breastmilk an infant consumes is a clear challenge. Furthermore, the nutrient content of a woman's breastmilk changes as her child ages, and even changes within a feeding episode.

Thus estimating intake of breastmilk and its nutrients in breastfed infants and young children is, often, not feasible. For this reason, assessment of breastfeeding is often limited to simple survey-based questions, and most dietary intake assessment of infants and young children 6 to 23.9 months is limited to intake of complementary foods and beverages only.

Even when dietary assessment is limited to complementary foods and beverages, several challenges remain. First, infants and young children do not have the communication or cognitive ability to report their own intake. Dietary assessment, then, typically relies on interviewing the child's primary caregiver(s), but several secondary caregivers or siblings could also be involved in feeding; thus primary caregivers' knowledge of the child's actual intake may be incomplete [59]. Furthermore, infants and young children, particularly in LMIC, experience frequent illness, and may not tolerate (or be perceived to tolerate) normal feeding, leading caregivers to alter feeding practices during or in recovery from illness [60]. Even in health, a young child's diet – especially in the first weeks and months of complementary feeding – changes rapidly. Any method designed to measure "usual" intake faces the challenge that usual intake may quickly be evolving, and infants have high inter-individual variation in diet [61]. Children may eat or be fed from a shared plate, making it difficult for his or her caregivers to know exactly what was consumed and in what quantities [62]. And even when children do eat from their own dish, young children may not finish their entire portion; they may leave uneaten food in their dish or may spill large quantities [59]. Lastly, caregivers in many LMIC have limited literacy and/or numeracy, making it impractical for them to keep records of food intake in real-time, instead necessitating observation in the home by trained personnel or relying on recall.

Despite the challenges, there are several dietary assessment methods that have been used to measure complementary feeding. Some common techniques are discussed in greater detail below.

2.5.1 Doubly Labeled Water

The use of doubly labeled water is the gold standard reference method for the measurement of energy intake [63]. Doubly labeled water is water whose hydrogen and oxygen have been replaced with isotopes that carry a detectable label. The doubly labeled water is consumed by the subject, and then the elimination of these isotopes – hydrogen in urine and oxygen in both carbon dioxide and urine – are measured and allow for the computation of energy expenditure, typically over a 7- to 14-day time period [63]. While doubly labeled water cannot estimate micronutrient or specific macronutrient intake, it is a least biased method for assessing energy intake.

2.5.2 Weighed Food Records

Weighed food records are considered “the most precise method available for estimating usual food and nutrient intakes of individuals” [58]. In some settings, respondents weigh and record the foods they consume over a specified period, for example 3 to 7 days. However, due to limited literacy and numeracy of respondents and/or caregivers in most LMIC, a trained data collector remains in the home, for example for a 12-hour period, and conducts the weighing and recording of foods consumed. While considered a gold standard, particularly for estimating individual nutrient intakes, weighed food records have a high respondent burden and, in some contexts, the practice of weighing foods before consuming is socially unacceptable. Alternative approaches to estimating portions consumed have been assessed and validated, including having the in-home observer use photographs or other methods to estimate amounts consumed [64-66].

2.5.3 Multiple-Pass 24-Hour Dietary Recall

Twenty-four hour dietary recall involves obtaining a detailed record of foods and beverages consumed in the previous day, and allows for estimation of macro- and micronutrients consumed. Gibson and Ferguson developed detailed methodology for an interactive, multiple-pass, 24-hour dietary recall that is appropriate for developing countries and has been described in detail elsewhere [67]. For the purpose of this dissertation, the methodology is described below in the context of infant and young child dietary recall.

Primary caregivers should attend an introductory training two or three days before their scheduled household visit. The purpose of this visit is to introduce caregivers to the methodology, while encouraging them not to alter child feeding on the observation day. Caregivers are also given a simple bowl or other contextually appropriate feeding dish with which to feed their child on the observation day. The observation day is the day whose intake is being assessed; ideally, it should be the day immediately following the training, but if necessary can be one day later. The observation day should always be the day immediately preceding the household visit. Caregivers also receive a pencil and a one-page food picture chart depicting common complementary foods, so that caregivers can "tick" foods as the child eats them to minimize recall bias.

On the day of the scheduled recall, a trained data collector visits the caregiver at home to collect the dietary recall. The dietary recall includes the following four passes: (1) Compile a list of all foods and beverages other than breastmilk and water consumed in the previous day; (2) Describe in detail, using pre-specified probing questions, all items listed in the first pass; (3) Estimate amounts consumed using methods (such as direct food weighing, food photographs, playdough, or using rice or water as proxies) that are pre-specified for each food; and (4) Review data from the previous three passes, and probe for between-meal consumption.

Mixed dishes that are common and unlikely to drastically differ from household to household are pre-specified as “standard recipes.” Any mixed dish that is reported in the dietary recall and has not be pre-specified as a standard recipe must be uniquely collected. This involves speaking with the person who prepared the dish, and collecting detailed information on the ingredients used including their amounts, and asking that person to estimate the final volume of the dish. For standard dishes, recipes are collected from women in the survey area. Ideally, at least four caregivers from at least four different areas will prepare the dish using ingredients, cooking materials, and cooking fuel provided by the survey team. Research assistants will record all ingredients and the amounts used, and will measure the volume and weight of the final prepared dish. Average ingredient proportions can then be calculated, including for different iterations of the recipe.

Food composition tables are required for converting foods and beverages consumed to nutrient intakes. Gibson and Ferguson emphasize that whenever possible, local food composition tables should be used [67].

2.5.4 Infant and Young Child Feeding Indicators

The methodologies described above are expensive and require lengthy periods of data collection, unless sample size is to be sacrificed. Furthermore, regardless of sample size, enumerators for these types of data collection should ideally have formal education in nutrition or a related field, and still need to undergo extensive training. As these demands are prohibitive for many governmental and non-governmental organizations, alternatives methods are required.

In 1991, as the result of an "informal meeting," a consensus was reached on breastfeeding indicators that could be "derived from household survey data" [68]. The publication of the Guiding Principles in 2003 precipitated calls for the development of indicators to "characterize caregiver behaviors related to feeding and the child's usual dietary intake" [69]. Indicators would be a useful, practical method of assessing current practices, identifying vulnerable populations for targeting interventions, and for monitoring and evaluation purposes [69].

Beginning in 2004, the *Working Group on Infant and Young Child Feeding Indicators* (henceforth referred to as the Working Group) had convened and begun the task of developing and validating indicators. The Working Group was a collaboration between experts from WHO Department of Child and Adolescent Health and Development; the Food Consumption and Nutrition Division of the International Food Policy Research Institute; the Program in International and Community Nutrition at the University of California, Davis; the Food and Nutrition Technical Assistance Project at FHI 360; and the United States Agency for International Development, and included experts as well from other partners [70, 71].

In 2006 and 2007, the Working Group published validation studies of two proposed indicators: feeding frequency and dietary diversity [70]. Specifically, the Working Group assessed the validity of feeding frequency as an indicator of complementary food energy intake, and the validity of dietary diversity as an indicator of micronutrient adequacy of the complementary diet. Dietary diversity was considered as the number of food groups consumed in the previous day, but four definitions were tested: 7 possible food groups with a 1 g minimum (if less than 1 g of a food was consumed then it did not count for the indicator), 7 possible food groups with a 10 g minimum, 8 possible food groups (with the additional group being fats/oils) with a 1 g minimum, or 8 possible food groups with a 10 g minimum [70]. Weighed food records was the reference method in three of the ten datasets, while 24-hour recall was the reference method in the remaining seven datasets [70, 71].

The Working Group found that, despite some heterogeneity by country, age group, breastfeeding status, and/or whether or not the child had consumed any fortified products, the indicators were generally correlated with their intended references [70, 71]. Feeding frequency – irrespective of whether the feeding episode was a meal or a snack – was significantly correlated with overall energy intake. However, there was no clear cutoffs identified for distinguishing low versus appropriate energy intake from complementary foods. Similarly, the number of food groups included in the diet was correlated with micronutrient adequacy. The authors found that the dietary diversity indicator using 7 food groups and a 1 g minimum was appropriate. In sensitivity/specificity analysis, the authors identified a cutoff of greater than or equal to 4 food groups as being appropriate for identifying young children with “adequate” dietary quality [70, 71].

In 2008 and 2010, the WHO published definitions and an implementation guide, respectively, for a series of age-specific infant and young child feeding (IYCF) indicators [72-74]. The indicators include eight core and seven optional indicators (Box 2-2); three of the core and five of the optional are concerned with breastfeeding practices [72] and build on the 1991 publication of breastfeeding-focused indicators [68]. Two optional indicators pertain to the feeding of breastmilk substitutes. The remaining five core indicators are complementary feeding-focused.

The indicators are an important tool for standardized IYCF assessment that is amenable to large-scale surveys. Since their development, they have been widely adopted [75]. However, they are not without limitations. Namely, the indicators are limited in their scope. In developing the indicators, the Working Group considered the Guiding Principles [11] as well as the WHO *Global Strategy for Infant and Young Child Feeding* [76] – two documents that acknowledge the multi-dimensionality of complementary feeding. The Working Group recognized this limitation, acknowledging that "[o]ther aspects of optimal feeding such as responsive feeding and adequate texture of food are more complex to assess, and work is still in progress to develop valid and reliable indicator definitions and measurement approaches for these" [72]. Notably, minimum meal frequency is the only indicator of complementary food energy intake. However, as described previously, complementary feeding recommendations were developed based on iterations of feeding frequency, energy density, and assumptions about gastric capacity. Absent indicators of actual amounts consumed and energy density, the information gained from the feeding frequency indicator is limited. Furthermore, the IYCF indicators are not consistently associated with nutritional status, raising questions about whether key complementary feeding facets are missed when the indicators are relied upon to describe complementary feeding adequacy [77].

2.5.5 Methods for Assessing Complementary Food Consistency

Energy and/or nutrient density can be estimated from 24-hour recall, or by collecting food samples for analysis [30], but these methods require considerable resources. Complementary food consistency, on the other hand, is not frequently measured, and methods that have been reported are either vague or prone to measurement error or bias. Aggarwal *et al*. used a "WHO teaching slide" to assess consistency of food [78]; the slide has two drawings of spoons tilted with the head of the spoon at a downward angle, one with a gruel-like substance mostly staying on the spoon and one with a gruel-like substances running off of the spoon [79]. Limitations of this method include potential for measurement error due to the poor quality of the drawing, and the potential for social desirability bias due to the spoons being labeled as "just right" and "too thick."

Many authors who discuss complementary food consistency do not directly specify their method of assessing consistency [31, 80-83] and did not respond to email inquiries. Language used in reporting results suggests that specific adjectives may have been used in a questionnaire; examples of such adjectives that have been used in reporting include: *liquid*/*gruel-like*/*semi-solid*/*solid* [80, 81], *solid*/*semi-solid*/*soft* [82], and *thick*/*thin*/*appropriate* [83]. However, qualitative research by Alive and Thrive in Ethiopia found that, caregivers tended to verbalize thicker consistencies than were observed in opportunistic observation of complementary feeding/food preparation [84]. Thus, survey questions that rely solely on adjectives to assess complementary food consistency are likely to result in measurement error and/or respondent bias. Two qualitative studies were identified that used maternal self-reported perceived change in complementary food consistency resulting from an intervention targeting consistency [85, 86]. Others have reported using "pretested" methods, but do not provide details. Specifically, Chauhan *et al*. reported that they utilized a "pretested interview…to collect information regarding…consistency of complementary foods," but gave no precise methodology; however, their results were reported as the giving of foods of "semi-solid consistency" and then listed several examples of foods that were considered to be semi-solid in consistency [87]. One additional study reported using "pre-tested indicators" but provided no further details [88].

One example was found of a study where 24-hour recalls were conducted and consistency was reported in terms of foods having "more" or "less water content" [32].

2.5.6 Methods of Estimating Portion Sizes of Infants and Young Children

Much of the literature around portion size measurement concerns weight loss and/or obesity prevention in industrialized countries [89, 90]. Portion size measurement methods have been categorized into three groups based on their purpose: measuring intake, understanding underlying cognitive mechanisms of portion size behavior (for example, self-efficacy, perception, and motivation), and for measuring behavior change [90]. Relevant to this discussion are portion size estimates for measuring intake and measuring behavior change, which can include the impact of environmental cues on behavior change. The focus hereafter will be on portion size estimation aids (PSEA) [90].

While weighing food is the gold standard for measuring intake, it is burdensome and intrusive to the subjects. Food photographs are one of the most oft-used PSEAs, and several tools – digital and printed – have been developed for use in both high- and low-income countries, and with all ages [91-97]. Flax *et al.* found that when women used digital photographs to estimate portion sizes, their responses were highly correlated with actual intake, but consistently underestimated intake; other PSEAs approximately equally over- and under-estimated intake [98]. Other PSEAs include food models and playdough [58, 67]. Recently, a group developed a tool termed the "International Food Unit" (IFU) which is a 64 cubic-centimeter (cm^3) cube that can be broken into eight, 8 cm^3 cubes to be used for demonstrating portion sizes for a variety of foods in a variety of forms [99]. When evaluated against other methods for estimating portion sizes, the IFU performed better overall, despite none of the subjects seeming to understanding that they can disassemble the unit [99]. Other researchers have developed and tested wearable technology that counts bites by sensing movement [100, 101], though the method has never been assessed in the context of complementary feeding (in which a caregiver feeds or assists a young child).

An additional, validated alternative to weighed food estimates has been estimation by trained observers [64]. However, the method still requires a trained observer to be in the home for all feedings [64]. While these alternatives may alleviate social unacceptability, they still requires highly trained data collectors and carry time and financial burdens.

All of the aforementioned strategies for estimating portion sizes have been in the context of an observed food record or a 24-hour recall, where specific foods consumed at specific meals are estimated. Very little published research could be found where attempts have been made to quantify usual or average portion sizes outside of a more rigorous dietary assessment. Sethi *et al*. assessed behavior change after an intervention targeting several complementary feeding behaviors and reported the percentage of mothers who “tried to increase the quantity of complementary foods” [88], though no details were available on how this was assessed. Researchers in Bangladesh observed feeding sessions and quantified “mouthfuls accepted” in efforts to assess the relationship between responsive feeding and intake [102-105].

2.6 Complementary Feeding Patterns

The Working Group cautioned that the “indicators for assessing feeding practices in children 6-23 months of age in particular should not be considered in isolation, because of the multi-dimensional aspects of appropriate feeding at this age” [72]. Nevertheless, researchers often carry out association studies with individual indicators to identify predictors or outcomes; results of these types of studies are difficult to interpret [75]. Minimum acceptable diet is a composite indicator that incorporates current breastfeeding, minimum dietary diversity, and minimum meal frequency into one dichotomous indicator [72].

2.6.1 Summary IYCF Indices

Authors have previously recognized the oftentimes counter-productivity of conducting parallel analyses of a handful of indicators, and developed indices to capture the multi-dimensionality of complementary feeding. A commonly used or adapted index is that developed by Ruel *et al*. The index, tabulated separately for infants 6 to 8.9 months, 9 to 11.9 months, and for children 12 to 36 months, assigns points based on the following feeding practices: breastfeeding, bottle avoidance, dietary diversity, food group frequency, and feeding frequency. With the exception of food group frequency – which is based on a 7-day recall – all are based on indicators with a 24-hour recall period. With its genesis in 2002, the index was found to be associated with anthropometric outcomes in several Latin American countries; the authors also identified several conditions that modified the effect of the index on anthropometry, such as age and wealth [106, 107].

Arimond and Ruel modified this index to adopt a slightly different scoring system for 7-day food group frequency, and used the resulting index to examine associations with anthropometric indicators in Ethiopia [108], and still found the index to be associated with anthropometry, and in particular with length- or height-for-age z score [108]. The authors also found that indicators of dietary diversity, when taken alone, were associated with anthropometry, and suggested that a dietary diversity indicator based on 24-hour recall only may be sufficient [108]. The index has since been adopted and/or modified several times, and has been used in both cross-sectional and longitudinal analyses to evaluate its association with nutritional status and/or growth [33, 80, 106-115].

A limitation of the summary index initially developed is that the authors gave "each element approximately equal weight, while recognizing that this weighting [was] somewhat arbitrary" [108].

2.6.2 Dietary Pattern Analysis

Latent variable modeling has been used as a means of characterizing dietary patterns, including in infants and young children in high-income countries; association studies can then assess predictors and outcomes of these overall patterns [116-121]. However, these analyses require dietary recall or food frequency data, and to our knowledge, this approach has never been applied to young children in LMIC.

2.7 Determinants of Complementary Feeding Practices

Complementary feeding is a complex behavior, and factors associated with it are likely to vary by context and range from individual- to environmental-level. For the purpose of this discussion, a framework termed the "COM-B System" developed by Michie *et al.* [122] will be used to discuss determinants of complementary feeding practices. The COM-B system states that capability (C), opportunity (O), and motivation (M) determine an individual's behavior (B). The domains are described below. For the purpose of this dissertation, we will limit the following discussion to evidence spanning multiple countries, or to evidence specifically from East Africa; qualitative findings are included. Many factors associated with complementary feeding may fall into more than one domain.

2.7.1 Capability

Behavioral determinants in the *capability* domain affect an individual's ability to act in a certain way, and can be physical or psychological [122].

Knowledge of recommended complementary feeding practices has been identified as a determinant of IYCF practices [123, 124]. Similarly, caregiver education, which may be a proxy for nutrition knowledge, has been positively associated with IYCF practices. Access to health care services and mass media, as well as having attended cooking demonstrations, have also been identified as determinants of IYCF that may reflect routes for nutrition education or imparting key skills [124, 125]. Paternal factors, including education and involvement in caring for children, have also been associated with improved complementary feeding [124, 126]. Paternal factors could also, potentially, be considered in the opportunity domain (for example, if fathers provide nutrient-dense foods for his family) or in the motivation domain (for example, if fathers support and normalize particular feeding practices but are not directly involved in feeding).

2.7.2 Opportunity

Behavioral determinants in the *opportunity* domain "lie outside of the individual that make the behavior possible or prompt it"; they may be physical or social [122].

An oft-cited factor associated with IYCF is food insecurity associated with one's financial and/or seasonal access to and availability of appropriate foods [123]. Alternatively, having a home garden may enable caregivers to practice improved IYCF [124]. Wealth, similarly, affects complementary feeding practices, particularly dietary diversity [124, 125]. Lack of other resources – such as cooking water [123] and/or cooking fuels – may also play a role in complementary feeding practices.

There has been some debate about the impact of maternal employment. In pooled analysis of Demographic and Health Surveys (DHS) from 50 countries, maternal formal and informal employment, compared to no employment, was associated with increased odds of meeting minimum dietary diversity, minimum meal frequency, and minimum acceptable diet; though formal employment may negatively impact continued breastfeeding after one year [127].

In terms of social opportunity, social and cultural norms about appropriate foods for infants and young children – and the ages at which they are appropriate – could also impact feeding practices. Women's empowerment is increasingly recognized as a social determinant of child feeding as well [123].

2.7.3 Motivation

Behavioral determinants in the motivation domain may be reflective and involve evaluation and planning, or may be automatic and involve emotions and impulses [122].

Caregivers' exposure to nutrition messages, cooking demonstrations, and mass media were previously cited in this section with respect to the capability domain, but are also considered in the motivation domain [123-126]. Child age is positively associated with child dietary diversity [125], which may reflect caregivers' perceptions about the appropriate age to give diverse foods. Lastly, religious or cultural fasting practices may affect complementary feeding [128].

2.8 Best Practices for Complementary Feeding Behavior Change

Interventions have long aimed at improving complementary feeding practices, as well as more distal outcomes like growth, in LMIC. Over the years, such interventions have been found to be effective in increasing knowledge of and improving complementary feeding practices [129, 130]. Programs that intervene on complementary feeding have also been reviewed for their effect on child growth and other health outcomes, with the general consensus of several reviews being that small but significant improvements can be realized, and that the magnitude of effect may be greater with the provision of complementary foods in food insecue populations [41, 131-134]. The goal of this discussion is to identify intervention components consistently associated with effective behavior change.

Conducting formative work to design complementary feeding behavior change interventions is a key component of succesful projects [135-137]. Formative work can include qualitative research such as focus group discussions, key informant interviews, and/or opportunistic observation with mothers, fathers, grandmothers, and health workers. Semi-quantitative or quantitative methods can also be employed in formative work, such as market surveys, or knowledge, attitude, and practice surveys. Formative work can also include thorough reviews of relevant literature. The goals of formative work include identifying specific complementary feeding behaviors to prioritize; identifying determinants – be they individual, interpersonal, societal, or environmental determinants – of the chosen behaviors; identifying target audiences for key messages and modes of communication; and pre-testing materials and/or messages for acceptability [135-137].

Successful programs often utilize multiple, strategic channels for outreach, including the use of mass media [136, 137] to allow for reaching larger audiences. Working within and strengthening existing systems for health message delivery can be keys to project sustainability and scalability [136]. Few published studies specify which, if any, theory or framework for behavior change was used, though various frameworks have been reported with success [136, 137]. Lastly, though infrequently done, projects should specify their theoretical project impact pathways and strive to measure factors along the impact pathway [135-137].

2.8.1 The Healthy Baby Toolkit

Researchers from Emory University and the Georgia Institute of Technology developed a set of tools – henceforth referred to as the Healthy Baby Toolkit (HBT) – designed to promote optimal nutrition in the first 1000 days of life [85, 86]. The HBT, pictured in Figure 2-1, consists of three items:

(a) A feeding bowl with (1) demarcations to promote age-appropriate portion sizes, and (2) symbols that promote age-appropriate feeding frequency for children 6 to 23.9 months, and to promote an additional meal per day for pregnant and lactating women;
(b) A slotted spoon, designed to cue caregivers to prepare thicker, more energy dense complementary foods that will not drip through the holes; and
(c) A counseling card that uses pictures and symbols to provide general instruction for use of the other tools, and that promotes dietary diversity and hygienic food preparation and handling.

The HBT was developed in Atlanta, Georgia "based on inputs from Sudanese and Ethiopian mothers with young children" [86], and was subsequently qualitatively evaluated in Bihar, India [85]; Western Kenya [86]; and Mchinji, Malawi [138]. In each setting, it has generally been found acceptable, and caregivers perceive it as being useful. The HBT promotes feeding frequency and portion sizes of the following amounts: 3 meals of 200 mL each per day for infants 6 to 8.9 months; 4 meals of 275 mL each per day for infants 9 to 11.9 months; and 4 meals of 340 mL each per day for young children 12 to 23.9 months. Assuming a complementary food density of 0.95 grams per milliliter (g/mL) and an energy density of 0.6 kcal/g [139], these specifications meet 96.1%, 130.9%, and 100.4% of the energy needs of a theoretical 97.5% of the population of 6- to 23.9-month old children (Table 2-3). The bowl also includes a line at the 500-mL mark, by which pregnant and lactating women are encouraged to eat one additional meal per day to support their pregnancy or lactation.

The HBT was developed based on the Health Belief Model [86]. The Health Belief Model explains an individuals' behavior or readiness for behavior change in terms of his or her perceptions about susceptibility to or severity of risks associated with a particular behavior, perceptions about the benefits and barriers of a particular behavior, self-efficacy, and cues to action [140].

2.8.2 Nutrition-Sensitive Interventions

Nutrition-sensitive interventions are those that address underlying causes of poor nutrition [141]. Nutrition-sensitive programs may address food insecurity, poverty, women's disempowerment, or inequitable/poor access to education, as examples. Nutrition-sensitive agriculture programs, of particular relevance to this dissertation, tend to target poor households that rely on subsistence farming in food insecure regions.

Nutrition-sensitive agriculture projects that promote orange-fleshed sweet potatoes (OFSP) that have been bio-fortified for vitamin A-richness have achieved improvements in vitamin A intake and status of young children in sub-Saharan Africa [142-146]. Sweet potatoes are relatively drought resistant, and tend to yield more energy per hectare than other staples [147]. Furthermore, sweet potato leaves can be consumed, and have a nutrition profile similar to other dark green, leafy vegetables. These characteristics make sweet potato an important food security crop [148, 149].

2.9 Knowledge Gaps

The period of complementary feeding sees rapid growth failure in LMIC [150]. Current indicators of IYCF are rather narrow in their scope, and fail to inform on complementary feeding practices that are relevant to energy intake. Portion size and complementary food consistency and/or energy density are poorly understood, and developing valid indicators should be a research priority. In fact, measuring these complementary feeding practices is only the first step; it is important to consider how they relate to feeding frequency, complementary food choices, responsive feeding, food hygiene, and other aspects of complementary feeding as outlined in the Guiding Principles. Programs that aim to change behavior must first identify behavioral determinants; identifying complementary feeding behavioral determinants is another research priority.

Based on these knowledge gaps, this dissertation aims to use data from East Africa to develop novel methods for assessing complementary feeding, to identify overall patterns and predictors of complementary feeding, and to assess strategies and impact pathways for complementary feeding behavior change.

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Table 2-1. Estimated total energy requirements, breastmilk energy intake, and complementary food energy requirements for infants and young children 6 to 23.9 months.

	Total Energy Requirements (kcal/d)		**Breastmilk Energy (BME) Intake (kcal/d)**			**Complementary Food Energy Requirements (kcal/d)**					
						Based on Average Energy Requirements			**Based on High Energy Requirements**		
	Average	High[1]	Low[2]	Average	High	Low BME	Average BME	High BME	Low BME	Average BME	High BME
6-8.9 months	615	769	217	413	609	398	202	6	552	356	160
9-11.9 months	686	858	157	379	601	529	307	85	701	479	257
12-23.9 months	894	1118	90	346	602	804	548	292	1028	772	516

Abbreviations: kcal/d, kilocalories per day; BME, breastmilk energy

[1]High estimates are averages plus 2 standard deviations

[2]Low estimates are averages minus 2 standard deviations

Note: this table has been adapted from Tables 1 and 3 in *Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs* by Dewey and Brown, 2003 [9]

Box 2-1. Ten Domains of the Guiding Principles for Complementary Feeding of the Breastfed Child [11]

1. Duration of exclusive breastfeeding and age of introduction of complementary foods
2. Maintenance of breastfeeding
3. Responsive feeding
4. Safe preparation and storage of complementary foods
5. Amount of complementary food needed
6. Food consistency
7. Meal frequency and energy density
8. Nutrient content of complementary foods
9. Use of vitamin-mineral supplements or fortified products for infant and mother
10. Feeding during and after illness

Table 2-2. Energy density and feeding frequency required for adequate complementary food energy intake.

	Complementary Food Energy Requirements (kcal/d)		**Assumed body weight (kg)**	**Functional Gastric capacity[3] (g)**	**Feeding Frequency**	**Energy density (kcal/g)**	
	Average[1]	**High[2]**				**Average Complementary Food Energy Requirements[1]**	**High Complementary Food Energy Requirements[2]**
6-8.9 months	202	356	8.3	249	2	0.41	0.71
					3	0.27	0.48
					4	0.20	0.36
9-11.9 months	307	479	9.5	285	2	0.54	0.84
					3	0.36	0.56
					4	0.27	0.42
12-23.9 months	548	772	11.5	345	2	0.79	1.12
					3	0.53	0.75
					4	0.40	0.56

Abbreviations: kcal/d, kilocalories per day; kg, kilograms; g, grams; kcal/g, kilocalories per gram

[1]Average estimates are based on average total energy needs and average breastmilk energy intake

[2]High estimates are based on high (average plus 2 standard deviations) total energy needs and average breastmilk energy intake

[3]Assumes a functional gastric capacity of 30 grams per kilogram body weight

Note: portions of this table are adapted from Table 3 in *Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs* by Dewey and Brown, 2003 [9]

Box 2-2. WHO Infant and Young Child Feeding Indicators [71]

Core Indicators:

1. Breastfeeding initiation
2. Exclusive breastfeeding
3. Continued breastfeeding
4. Introduction of solid, semi-solid, or soft foods
5. Dietary diversity
6. Minimum meal frequency
7. Minimum acceptable diet
8. Consumption of iron-rich or iron-fortified foods

Optional Indicators

9. Children ever breastfed
10. Continued breastfeeding at 2 years
11. Age-appropriate breastfeeding
12. Predominant breastfeeding under 6 months
13. Duration of breastfeeding
14. Bottle feeding
15. Milk feeding frequency for non-breastfed children

Figure 2-1. Healthy Baby Toolkit [139].

Table 2-3. Assumptions and complementary feeding recommendations made by the Healthy Baby Toolkit.

	High Complementary Food Energy Needs[1]	Portion Size (mL)	Assumed Density (g/mL)	Assumed Energy Density (kcal/g)	Feeding Frequency	Energy (kcal)	Percent of Complementary Food Energy Needs Met
6-8.9 months	356	200	0.95	0.6	3	342	96.1
9-11.9 months	479	275	0.95	0.6	4	627	130.9
12-23.9 months	772	340	0.95	0.6	4	775.2	100.4

Abbreviations: SD, standard deviations; CF, complementary Foods; mL, milliliter; g/mL, grams per milliliter; kcal/g, kilocalories per gram

[1]High complementary food energy needs based on average plus 2 standard deviations total energy needs and average breastmilk energy intake.

NOTE: The information in this table is adapted from information provided by personal communication with Amy Webb Girard [139].

Chapter 3 - Data Sources

Data for the research included in this dissertation were collected from two separate, one-year longitudinal project evaluations: one in Malawi and one in Ethiopia. Both projects include a component to evaluate the "Healthy Baby Toolkit" (HBT).

3.1 Operations Research in Mchinji, Malawi

In 2015, Concern Worldwide (CWW) utilized a Care Group approach to disseminate health and nutrition education to households in rural communities in the Mchinji district in central Malawi. The Care Group approach utilized by CWW has been detailed elsewhere [1]. Briefly, a Care Group is a group of 12 to 15 volunteer "Lead Mothers" who meet for routine (for example, monthly) trainings that cover topics related to nutrition; water, sanitation, and hygiene; family planning; or vaccinations, to name some examples. The Lead Mothers are then responsible for visiting 10 to 15 households in their neighborhood to share the message; in some cases she may use educational tools or illustrations. Lead Mothers are trained by community "Promoters." Promoters are volunteers identified by CWW, may be either male or female, and tend to have higher levels of education. Promoters are directly trained by CWW staff, and are responsible for 2 to 4 Care Groups each; this model is represented in Figure 3-1. Households were eligible for CWW's programs if they had a pregnant woman or a child under 5 years of age. This model for community-based health messaging reaches a large number of beneficiaries, and relies heavily on committed volunteers to do so [1].

Researchers from Emory University agreed to consult on operations research that CWW was conducting to evaluate the impact of including the HBT into their usual Care Group model for nutrition education. The operations research consisted of a baseline and endline survey of households in the Care Groups, with Care Groups being randomized to receive either the standard Care Group program (control), or the standard Care Group program and the HBT (intervention). At the time of the operations research, there were 183 Care Groups, 172 of which included had at least 8 documented volunteer Lead Mothers and were considered eligible. Care Groups were the unit of randomization, and the primary sampling unit. Lead Mothers then identified eligible households, which were defined as households participating in the Care Group program and having at least one child at between 6 and 17 months of age. With a desired sample size of 1,300 – powered to detect differences in anthropometric outcomes – 60 Care Groups were randomly selected to participate in the evaluation, based on the assumption that an average of 10 Lead Mothers would participate in identifying eligible households and that approximately 20% of the households in her purview would be eligible.

A baseline survey was completed in July to August 2015. During data collection, the target sample size was surpassed after 51 of the 60 Care Groups had been sampled, and thus data collection was stopped. After the baseline survey, the 51 Care Groups were randomized to either control or intervention; however only data from the baseline survey is used in this dissertation and therefore the intervention is not relevant. As researchers from Emory University were subsequently cleaning and analyzing baseline data, it was discovered that households from two additional Care Groups had been erroneously sampled. This likely occurred because Promoters were involved in recruiting Lead Mothers, and Promoters may have accidentally included Lead Mothers from Care Groups that were not selected for the survey. Thus, 53 total Care Groups are used in these analyses, with Care Groups treated as clusters.

An endline survey was conducted in June 2016, which sought to interview the same households as had been enrolled at baseline. However, only data from the baseline survey are used in this dissertation. The baseline and endline surveys collected similar information, and included the following sections:

a) Basic identification and household sociodemographic characteristics, including caregiver and head of household education and occupation and ownership of durable goods
b) Household food insecurity (measured via the Household Food Insecurity Access Scale [2]).
c) Access to water and sanitation facilities
d) Infant and young child feeding practices, including World Health Organization (WHO) indicators for minimum dietary diversity, minimum meal frequency, and minimum acceptable diet [3, 4]; novel indicators described later in this dissertation were also developed for estimating usual portion size and complementary food consistency.
e) Participation in Care Groups
f) Receipt of HBT items (endline only)
g) Knowledge of young child feeding recommendations
h) Child anthropometry

The project was funded by the Government of the Republic of Malawi’s Nutrition, HIV, and AIDS Project’s, and specifically by the Support to Nutrition Improvement Component A; funding for this program came from the World Bank.

3.2 Quality Diets for Better Health Project in Southern Ethiopia

Quality Diets for Better Health (QDBH) is a nutrition-sensitive agriculture project in southern Ethiopia; implementation is led by the International Potato Center (CIP) in partnership with People in Need (PIN), Emory University, the Southern Agricultural Research Institute, and with support from local government offices. Funding for the project is provided by the European Union. The project aims to improve diets, primarily of infants and young children or pregnant and lactating women. Project activities fall into three overarching goals: (1) to promote homestead production of orange-fleshed sweet potatoes (OFSP) as a programmatically sustainable, food-based source of vitamin A and energy; (2) to deliver nutrition education through volunteer-led groups called Healthy Living Clubs (HLCs) modelled after the government's Health Extension Program; and (3) to develop an OFSP value chain that will deliver commercial products to rural markets and support income generation of OFSP-producing farmers. Forty-one *kebeles* (administrative units with an approximate average of 1000 households) in three *woredas* (larger administrative units) in the Sidama and Gedeo zones of the Southern Nations, Nationalities, and Peoples' Region (SNNPR), Ethiopia were selected for participation. The project is designed for scale-up over the course of 54-months, with project activities implemented in 13 *kebeles* in the first year, 29 *kebeles* in the second year, and the full 41 *kebeles* in the third year when the project will shift some focus to sustainability and value chain development. An additional goal of the project is to assess the impact of the HBT, which will be distributed in select *kebeles* only.

A one-year, longitudinal study was designed to evaluate the effect of the project on vitamin A and energy intake of infants and young children. Of the 41 *kebeles* selected to participate in QDBH, 26 were identified as eligible for project implementation in the first year based on having at least moderate potential for sweet potato agriculture and an absence of other nutrition-specific or nutrition-sensitive programs. Of the 26 eligible *kebeles*, 6 were randomly selected for receiving the partial intervention, 7 randomly selected for full intervention, and 7 randomly selected to act as a control group. The partial intervention consisted of standard project activities, including promotion of homestead OFSP production, nutrition education, and support to local health and agriculture systems. In addition to all activities included in the partial intervention, the full intervention included the HBT. The project will be implemented in *kebeles* in the control group in or after year 3, after data collection for the project evaluation has taken place.

In approximately September 2017, PIN undertook a complete listing of all households residing in the 26 *kebeles* that were eligible for QDBH project implementation in its first year, including all 20 *kebeles* participating in the study described here. The household listing included whether any woman in the home was pregnant, and if so her approximate gestation, or whether there was any child under 2 years of age. The household listing was used to identify priority households for the HLCs in the full and partial intervention kebeles. Households with women in their last trimester of pregnancy or with infants under 6 months were preferentially enrolled; households with women in earlier pregnancy or with young children over 6 months were also eligible. An additional eligibility criteria for HLC participation was having approximately 30 square meters of land where OFSP could be planted. Shortly after the household listing was complete and households were enrolled in HLCs in the intervention kebeles, CIP and PIN distributed 150 OFSP vines to participating households, and provided basic instruction on how to plant and maintain the OFSP.

A target sample size of 600 was sought for the longitudinal evaluation based on the following expected parameters: anticipated differences in energy intakes of 100-150 kilocalories (kcal), differences in vitamin A intake of 200-350 microgram (mcg) retinol activity equivalents (RAE), 10-15% coefficient of variation, an intraclass correlation coefficient (ICC) of 0.05, and 30% loss to follow-up.

Households were enrolled and completed a baseline questionnaire in December 2017 to January 2018 (Table 3-1). In either partial or full intervention kebeles, data collectors worked with local project staff and leaders to identify eligible households, defined as those participating in an HLC who had an infant under 6 months of age. In the 7 control kebeles, data collectors used the household listing and worked with local community health and agriculture workers and/or government leaders to identify eligible households, defined as any household with an infant under 6 months. Based on the household listing, we anticipated 601 eligible households; anticipating some refusal to participate and given a target sample size of 600, we enrolled every eligible household in which the caregiver and household head (if available at the time of the interview) provided informed consent to complete the baseline survey and participate in the one-year study with three data collection timepoints.

A midline survey occurred approximately six to seven months later, and an endline survey approximately six months after that. At the time of the midline and endline surveys, all children were at least six months of age, and the surveys included multiple-pass 24-hour dietary recall of infant diets following the methodology outlined by Gibson and Ferguson [5]. According to this method, we requested that caregivers attend a “Mother Training” two or three days prior to their scheduled household visit. These sessions were held at an accessible location, such as a health post, school or church. At this visit, trained data collectors administered a short questionnaire. Specially trained pairs of data collectors recorded the child's weight in kilograms and recumbent length in centimeters, taking duplicate measures of each and a third measurement if the difference between the first and second exceeded 0.5 kilograms for weight or 1.0 centimeters of length. At midline, if the caregiver attending was the child's biological mother, then her weight and height were also recorded. Also at this visit, a specially trained data collector introduced caregivers to the multiple-pass 24-hour recall methodology. Caregivers were provided with a basic, plastic bowl and asked to use it to feed her child on the assigned "observation day" – the day immediately preceding the household visit on which the child's intake would be measured. Asking the caregiver to use the separate bowl enables her to estimate amounts consumed. Caregivers also received a pencil, and a color picture chart with a variety of commonly consumed foods and dishes. The trained data collector explained that the caregiver could use the pencil to "tick" foods as they were consumed by the child on the observation day; the trainer then demonstrated and gave caregivers a chance to practice.

A second group of trained data collectors conducted the household visits two or three days after the initial training and administered an additional survey, which included infant and young child feeding indicators.

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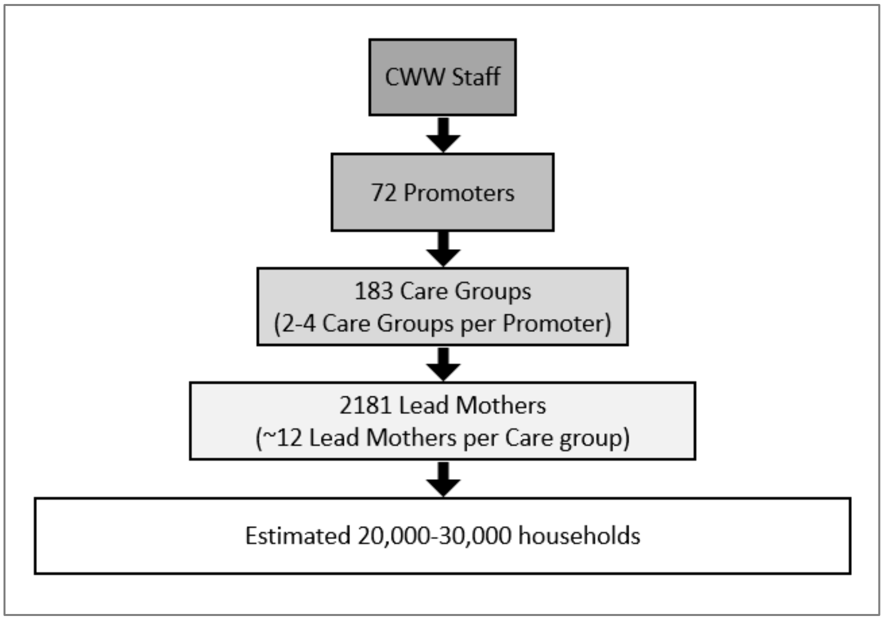

Figure 3-1. Care Group model used by Concern Worldwide.

Table 3-1. Survey Modules included in the QDBH longitudinal study at baseline, midline, and endline.

Survey Module	**Baseline** (n=605)	**Midline** (n=548)	**Endline** (n=523)
Household identification and contact information	✓	✓[1]	✓[1]
Roster of all household members and their basic socio-demographic characteristics	✓		
Housing characteristics and access to utilities	✓		
Household ownership of durable goods	✓		
Household ownership of livestock	✓		
Agricultural practices	✓		
Sweet potato agricultural practices	✓	✓[2]	✓[2]
Household food insecurity	✓	✓[1]	✓[1]
Basic market access and food purchasing	✓		
Water, sanitation, and hygiene	✓		
Household fasting practices	✓		
Household and caregiver dietary diversity	✓	✓[1]	✓[1]
Perinatal health care access	✓		
Infant health and feeding practices	✓	✓[2]	✓[2]
Caregiver knowledge of infant and young child feeding recommendations	✓	✓[1]	✓[1]
Infant anthropometry	✓	✓[1]	✓[1]
Caregiver anthropometry		✓[1]	
Multiple-pass 24-hour dietary recall		✓[2]	✓[2]

[1]Assessed at Mother Training
[2]Assessed at household visit

Chapter 4 - Relative Validity of Indicators of Usual Portion Size and Complementary Food Consistency

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Abstract

The aim of this research was to evaluate the relative validity of novel indicators of usual portion size and complementary food consistency in a sample of 6- to 13-month old children in southern Ethiopia. As part of a household survey, we collected indicators of complementary feeding, including two novel test indicators of portion size and complementary food consistency. Caregivers estimated their child's usual portion size using uncooked rice, and selected which of five photographs of porridges of varying consistencies most closely matched the food her child ate. We calculated predicted energy intake by two test methods: by combining indicators of feeding frequency, portion size, and consistency, or of feeding frequency and portion size only. At the same visit, trained enumerators conducted a multiple-pass 24-hour dietary recall of the index child's diet, from which we computed energy intake from and energy density of complementary food, as reference values. We assessed the relative validity of test indicators by computing correlation coefficients and areas under Receiver Operating Characteristic (ROC) curves (AUC) for identifying children whose energy intake or complementary food energy density were below recommended values. Estimated portion size was significantly correlated with total energy intake from complementary foods, and with both average energy intake and quantity of food consumed per feeding episode ($r=0.42$, 0.45, 0.44, respectively, all $p<0.001$). The consistency test indicator was significantly but weakly correlated with average energy density of complementary foods ($r=0.10$, $p<0.05$) and with average energy density of porridges ($r=0.24$, $p<0.001$). All indicators predicted whether or not a child received inadequate energy from complementary foods; predicted energy intake combining feeding frequency, portion size, and consistency was significantly better at predicting inadequate energy intake than feeding frequency alone in infants 6 to 8.9 months ($p<0.01$) and 9 to 11.9 months ($p=0.03$). In

conclusion, indicators of portion size are valid and useful in identifying children with inadequate energy intake from complementary foods; the validity and usefulness of an indicator of consistency is less clear.

Key messages

1. Energy intake from complementary foods is a function of feeding frequency, energy density of complementary foods, and amount consumed per feeding.
2. Caregivers’ estimate of usual portion size using uncooked rice is a valid indicator of energy intake and amount of food consumed, relative to multiple-pass 24-hour dietary recall.
3. The validity of complementary food consistency assessed with porridge photographs as an indicator of energy density is less clear.
4. Portion size and feeding frequency combine to better predict young children with inadequate energy intake from complementary foods, compared to feeding frequency alone.

4.1 Introduction

Appropriate infant and young child feeding (IYCF) practices, including breastfeeding, quantity and quality of complementary foods, responsive feeding, and hygienic preparation and storage of complementary foods, are foundational for optimal growth and development [1]. The most rigorous methods for dietary assessment demand substantial inputs of time, skilled workers, and money, making them resource-prohibitive for many purposes. Simple, valid indicators are required to enable population-level IYCF assessment, program monitoring and evaluation, and research on determinants and outcomes associated with IYCF [2]. World Health Organization (WHO) IYCF indicator definitions were published in 2008, with an ensuing implementation guide in 2010 [3, 4]. The indicators have since been widely adopted, but are limited in their scope, covering only select facets of IYCF [5].

Overall energy intake from complementary foods is a function of feeding frequency and energy intake per feeding episode; energy intake per feeding episode is a combination of energy density and amount of food consumed [6, 7]. The validity of meal frequency has previously been assessed in ten datasets from nine countries in Africa, Asia, and Latin America [8, 9], but portion size and energy density are difficult to assess in a questionnaire. Portion size estimation in the context of 24-hour dietary recall typically uses direct food weighing, food photographs, playdough, or household units of a standard size [10]. Complementary food consistency has been used as a proxy of energy density. Jones reported using photographs of common complementary foods of different consistencies, also in the context of a 24-hour dietary recall [11]. Complementary food consistency has been assessed in surveys; detailed methods for doing so are often not described in detail, but results have been reported as adjectives such as *liquid/gruel-like/solid* [12, 13] or others [14-17]. However, in southern Ethiopia, caregivers verbally overestimated complementary food thickness compared to consistencies opportunistically observed [18].

Relative validity is the comparison of a test method with a reference [19]. The objective of the present research was to examine the relative validity of novel approaches to assess usual portion size and complementary food consistency in a sample of 6- to 13-months old children in southern Ethiopia, with multiple-pass 24-hour dietary recall as the reference method.

4.2 Methods

4.2.1 Study setting and population.

Data for this study were collected as part of a longitudinal evaluation of the *Quality Diets for Better Health* project in the Sidama and Gedeo zones in the Southern Nations, Nationalities, and Peoples' Region (SNNPR), Ethiopia. *Quality Diets for Better Health* is an integrated project that promotes vitamin A-rich orange-fleshed sweet potatoes (OFSP) and delivers community-based nutrition education to promote optimal complementary feeding practices [20]. A three-arm cluster-randomized controlled trial was designed to evaluate the program; including a control group, a partial intervention group that received OFSP vines and nutrition education, and a full intervention group that received OFSP vines, nutrition education, and a feeding bowl and spoon designed to promote recommended portion size and complementary food consistency [21, 22]. Nutrition education in both intervention groups included messaging on age-appropriate portion size and complementary food consistency.

Households with infants under 6 months were eligible for enrollment in a baseline survey in December 2017 and January 2018; follow-up surveys were conducted 7 and 13 months later in August 2018 and February 2019, respectively. Data on complementary feeding at the first follow-up survey and select demographic characteristics assessed at baseline were used in these analyses.

4.2.2 Data collection.

The baseline survey was conducted when all infants were under 6 months, and included data on household demographic characteristics and breastfeeding practices. At the first follow-up, all children were at least 6 months of age. In addition to survey questions, this follow-up visit included an interactive, multiple-pass 24-hour recall of infant diets using methodology described by Gibson and Ferguson [10]. Two or three days before their scheduled household visit, caregivers attended a “Mother Training” with approximately 10 to 15 other caregivers. At the meeting, trained research assistants introduced caregivers to the multiple-pass 24-hour recall methodology, and provided caregivers with a separate bowl with which to feed their infant on the observation day to enable portion size estimation. The observation day is the day whose intake is measured, and is the day immediately preceding the household visit. Caregivers also received a picture chart with common complementary foods and a pencil so that they could mark foods as they were given on the observation day. Caregivers were encouraged not to change what they fed their infant on the observation day. During this introductory meeting, research assistants administered a survey to assess household food security, recent illness, nutrition knowledge, age of introduction of various complementary foods and liquids, and project participation; anthropometric measurements were also collected.

At the household visit, research assistants used novel methods of estimating usual portion size and complementary food consistency. To estimate portion size, caregivers were first asked whether their child normally eats from a shared dish, or receives his or her own dish. For children who receive their own dish, caregivers used uncooked rice to estimate a *typical* portion served to the child; this volume of uncooked rice was then transferred to a graduated cylinder and the volume recorded to the nearest milliliter (mL). The caregiver was asked if the child typically leaves any food remaining, and if so, was asked to use uncooked rice to estimate the amount of food uneaten, such that the amount consumed could be calculated as the volume remaining subtracted from the volume served. If the caregiver answered that the child typically eats from a shared dish, then the caregiver used the uncooked rice to estimate the amount consumed. To estimate complementary food consistency, caregivers were shown five numbered photographs of porridges with varying energy densities (Figure 4-1) and were asked to select which photograph most closely resembled the consistency of complementary foods eaten by their child. The energy densities of the photographed porridges were 0.08 kilocalories per gram (kcal/g), 0.36 kcal/g, 0.66 kcal/g, 0.94 kcal/g, and 1.25 kcal/g. These methods of assessing portion size and complementary food consistency are referred to as "test indicators." Research assistants also collected data on WHO indicators of feeding frequency, dietary diversity, and bottle use in the previous day [3, 4].

After IYCF indicators were assessed, research assistants proceeded with the multiple-pass 24-hour recall of infant diets. The recall consists of the following four passes: (1) compile a list of all foods and drinks other than breastmilk and water that the infant consumed in the previous day; (2) obtain detailed descriptions of foods and beverages consumed using pre-specified probing questions; (3) estimate amounts consumed using interactive methods (such as playdough, food photographs, direct weighing of select foods, and using uncooked rice or water to estimate volumes) that were pre-specified for each food type; and (4) review the data already collected with probing questions for any corrections or additional consumption between eating episodes. Based on formative work conducted prior to the survey, a list of common mixed dishes were pre-specified as standard recipes. For mixed dishes not identified as standard recipes, research assistants requested that the person who prepared the dish describe each ingredient and estimate the amounts of each ingredient using methods described above during the household interview. All porridges/gruels were collected as unique household recipes in order to assess differences in energy density of these foods. After all household interviews were completed, standard recipes were collected by inviting 4 women in between 2 to 4 communities (depending on the frequency with which the dish was actually consumed in the area) to prepare the dishes. At this time, research assistants recorded and weighed all ingredients used in preparing the dish; all ingredients, cooking utensils, and cooking fuels were provided by the study team. A food composition database was developed using pre-existing food composition tables from Uganda [23], Ethiopia, or, where necessary, the United States Department of Agriculture [24]. A conversion factor database was developed by combined primary collection of conversion factors and pre-existing conversion factors from neighboring countries.

We computed predicted energy intake by taking the product of indicators of portion size (mL/feeding) and feeding frequency (feedings/day) while assuming an energy density of 1 kcal/g and a complementary food density of 1.05 g/mL, which is the density of porridge prepared with maize flour according to the INFOODS Density Database Version 2.0 [25]. We also computed a predicted energy intake using the same formula, but applying the energy density of the photograph selected by the caregiver rather than assuming a standard energy density.

4.2.3 Analytical Approach.

Nutrient intakes from multiple-pass 24-hour dietary recall were used to estimate total energy intake from complementary foods and average energy intake per feeding episode (both in kcal); quantity of complementary food consumed per eating episode (in grams); average energy density of complementary foods (in kcal/g); and average energy density of porridges/gruels (in kcal/g). If a child consumed no energy-containing complementary food or liquid, then his or her energy intake was set to 0 kcal, but energy density was considered missing. Children were classified as receiving sufficient complementary food energy if they had at least the following complementary food energy intake: 202 kcal for 6 to 8.9 months, 307 kcal for 9 to 11.9 months, and 548 kcal for 12 months and above [26]. Children were classified as meeting recommended minimum energy density if the average energy density of their complementary foods was 0.8 kcal/g or above [7]. These values were considered the reference method for assessing the relative validity of the test indicators.

We assessed the distributions of continuous variables for normality based skewness, kurtosis, and visual inspection of histograms. To assess the relative validity of caregivers' estimates of usual portion size, we examined the correlation between the estimated portion size and each of the following: total energy intake from complementary foods, average energy intake per eating episode, and average grams of complementary food consumed per eating episode. We also present the correlation between feeding frequency and overall energy intake as a reference. Pearson's correlation coefficients were used for normally distributed variables, and Spearman's Rank correlation coefficients were used for non-normally distributed variables. We computed correlations for the full sample, but also for the following sub-groups: restricted only to children whose caregiver reported that the child had consumed solid, semi-solid or soft foods in the previous day; by age category (6 to 8.9 months, 9 to 11.9 months, and 12-13.9 months); whether the child eats from a shared dish versus his/her own dish; by intervention group; by Sidama versus Gedeo zone; whether or not the child had been sick in the previous day; whether or not anyone in the household had fasted in the previous day; and whether or not the caregiver had completed cycle 1 in school (equivalent to grade 4). We used Fisher's r-to-z-transformation to test whether correlation coefficients differed between these strata.

Using the conversion of 1.05 g/mL [25], we converted caregivers' estimates of usual portion size from milliliter to grams to assess agreement between estimated portion size and average amount of food consumed per episode, both in grams, using a Bland-Altman plot.

We computed polyserial correlation coefficients between the photograph selected to represent complementary food consistency (numbered 1 through 5) and average energy density of complementary foods consumed, as well as the average energy density of porridges/gruels only. We also examined polyserial correlation coefficients in the same sub-groups as previously stated.

We estimated Receiver Operating Characteristic (ROC) curves to evaluate the ability of the consistency photograph indicator to identify infants whose average energy density of complementary foods was below the recommended 0.8 kcal/g. Similarly, ROC curves were used to evaluate the abilities of each of the three indicators – feeding frequency, photograph of complementary food consistency, and estimated portion size – and of the predicted energy intakes to identify infants not meeting recommended complementary food energy intakes. These ROC curves were estimated separately for infants 6 to 8.9 months, 9 to 11.9 months, and 12 to 13.9 months based on their having different cutoffs for adequate complementary food energy intake. An area under the curve (AUC) statistically greater than 0.5 is considered significant. We also tested whether the AUC of the new indicators (portion size and complementary food consistency) and of the predicted energy intakes were a statistical improvement over the AUC of feeding frequency alone using the ROCCONTRAST statement in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

We conducted a sensitivity analysis by computing correlation coefficients for the portion size test indicator, as well as the AUC computation, after excluding children with no complementary food energy intake. We did not repeat the computation of polyserial correlation coefficients for the consistency indicator because the original analysis already excluded those infants on the basis of having no reference energy density.

A p-value less than 0.05 was considered statistically significant. All analyses were conducted in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

4.2.4 Ethical Approval.

Ethical approval for this work was obtained from Emory University's Institutional Review Board, and from the Southern Nations, Nationalities, and Peoples' Regional Bureau of Health Ethical Review Committee. The trial for which the data were collected is registered with ClinicalTrials.gov, ID NCT03423472.

4.3 Results

Overall, 605 households were enrolled at baseline and 548 (90.6%) completed the first follow-up survey and were eligible for the analyses described here. Their general characteristics are shown in Table 4-1. The children ranged in age from 6 to 13 months, with an average age of 10.0 ± 1.7 months. A majority (59.1%) of the sample lived in the Gedeo zone, and 52.1% of caregivers had completed at least cycle 1 in school.

At follow up, only one child was not breastfed, and 96.2% received solid, semi-solid, or soft foods in the previous day. A majority of caregivers (87.3%) reported that the child typically receives his or her own feeding dish. Overall, the mean number of feeding episodes, which does not differentiate between meals and snacks, was 3.6 ± 1.7. Almost 20% of children consumed thin complementary foods (photograph 1 or 2), 65.1% consumed medium consistency matching photograph 3, and just over 15% consumed thicker complementary foods (photograph 4 or 5).

Portion size, energy intake from complementary foods, average energy intake per feeding episode, amount of food consumed per eating episode, and energy density were all right skewed. Therefore, we present summary characteristics as medians and interquartile ranges (IQR). The median portion size for the entire sample was 55 (IQR 40, 80) mL; the age-group specific median portion sizes were lowest in the youngest age group (50 [IQR 35, 70] mL) and highest in the oldest age group (62 [IQR 45, 80] mL). Just over half (50.6%) of the sample had adequate energy intake from complementary foods, but this proportion was highest in infants 6 to 8.9 months (68.6%) and lowest in children over 12 months (25.6%). The median energy density of complementary foods was 1.50 (IQR 1.20, 1.89) kcal/g, and a high proportion (95.5%) consumed complementary foods with an average energy density of at least above the recommended 0.8 kcal/g [7].

Due to the skewness of the data, we used Spearman Rank correlation coefficients to assess the relative validity of caregivers' estimate of usual portion size. Caregivers' estimated portion size correlated significantly and positively with total energy intake from complementary foods ($r=0.42$, $p<0.0001$), average energy intake per eating episode ($r=0.45$, $p<0.0001$), and average food consumed per eating episode ($r=0.44$, $p<0.0001$; Table 4-2). Estimated portion size was uncorrelated with overall energy intake from complementary foods only in children who had been sick in the previous day; all correlations were significant in every other sub-group. The strength of the correlation was significantly weaker in the partial intervention group ($r=0.29$, 0.34, and 0.29 for total energy intake, energy intake per eating episode, and amount of food consumed per eating episode, respectively), and in children who had been sick the previous day (r=0.15, and 0.22 for total energy intake and energy intake per episode, respectively). The correlation between estimated portion size and energy intake per episode was also significantly lower in the Gedeo zone (r=0.38) compared to the Sidama zone (r=0.54).

The Bland-Altman plot (Figure 4-2) shows the agreement between estimated portion size and average amount of food consumed per episode. Portion size estimates became less precise with increasing intake. However, the average difference between the two methods was 3.5 ± 36.3 grams, and 4.6% of observations fell outside the limits of agreement (mean difference ± 1.96 standard deviations).

Feeding frequency was correlated with overall energy intake from complementary foods (r=0.41, p<0.0001); its correlation was weaker in the Gedeo zone (r=0.30) and among children who had not been sick in the previous day (r=0.35; Table 4-3).

The complementary food consistency test indicator was weakly correlated with average energy density of complementary foods (r=0.10, p<0.05) and with average energy density of porridges/gruels (r=0.24, p<0.001). Though none of the sub-groups' correlation coefficients differed significantly from one another, there was considerable heterogeneity and the correlations were non-significant among several of the sub-groups that were tested (Table 4-4). The complementary food test indicator did not significantly identify children whose average energy density of complementary foods fell below 0.8 kcal/g (AUC 0.60 [95% CI 0.49, 0.71]), though it was able to identify children whose average porridge energy density failed to meet this threshold (AUC 0.63 [95% CI 0.53, 0.73]).

In ROC curves, each indicator significantly predicted the young children with low complementary food energy intake with the exceptions of feeding frequency among infants 6 to

8.9 months and the consistency test indicator among young children 12 months and above, both of whose lower 95% confidence limit was the null value of 0.50 (Table 4-5). When compared to feeding frequency, the consistency test indicator performed significantly worse in children 9 to 11.9 months (AUC contrast = -0.12, $p<0.01$) and 12 to 13.9 months (AUC contrast = -0.22, $p<0.001$). However, predicted energy intake based on two and three indicators outperformed feeding frequency along in children 6 to 8.9 months (AUC contrast = 0.19 and 0.20 for two and three indicators, respectively, both $p<0.01$) and in children 9 to 11.9 months (AUC contrast = 0.09, $p<0.01$ for two indicators, and AUC contrast = 0.07, $p=0.03$ for three indicators). In the oldest age group, the AUC of predicted energy intakes were of the greatest magnitude, though they were not significantly different from the AUC of feeding frequency alone.

Eleven children consumed no complementary foods or beverages (other than water) and were excluded from the analytical sample in sensitivity analyses. These results can be found in Supplemental Table 4-1 through Supplemental Table 4-3. Generally, excluding the eleven children with no energy intake from complementary food had little effect on the results. However, among children who had been sick in the previous day, portion size was significantly correlated with total energy intake from complementary foods after the exclusion of those with no energy intake, though the strength of the correlation was still attenuated ($r=0.27$, $p<0.01$) when compared to children who had not been sick in the previous day ($r=0.48$, $p<0.001$). After the exclusion, the correlation between feeding frequency and energy intake from complementary foods was not significant among children eating from a shared dish, and was significantly weaker than the correlation among children receiving their own dish ($p<0.05$).

4.4 Discussion

Caregivers' estimates of usual portion size were correlated with energy intake from complementary foods and amount of food consumed per feeding episode in this sample of children aged 6 to 13 months in southern Ethiopia. The correlation was attenuated in the partial intervention group compared to the full intervention and control groups. Like participants in the full intervention, participants in the partial intervention group were exposed to nutrition messages about age-appropriate portion sizes for infants and young children. However, unlike the full intervention, partial intervention participants received no specific tools to instruct them on appropriate portion size. Rather, portion size education messages used *buna* (coffee) cups to make recommendations to caregivers; *buna* cups are a standard size and shape throughout the country, with each one equaling approximately 70 to 75 mL. Conversely, children in the full intervention received a marked feeding bowl and spoon to promote specific portion sizes and consistency. It is possible that the portion size education without specific tools influenced caregiver responses differently than the full project intervention or no intervention at all.

Correlations between estimated portion size and energy intake were also weaker among children who had been sick in the previous day. This could be due to the fact that caregivers were queried on their child's usual portion size, but acute illness may have impacted their feeding practices or child intake on the day in question. Eleven children received no complementary foods or liquids other than water in the previous day. Of these 11, 3 had missing data on portion size and were not included in the analyses. All of the remaining eight children who were excluded in the sensitivity analysis had been sick in the previous day. The difference in strength of the correlation between sick and well children persisted, but was less stark in sensitivity analyses excluding children whose complementary food energy intake was zero.

The Bland-Altman plot showed that the precision of estimated portion size was poorer with increasing portion size. Similar findings have been noted by others in the context of portion size estimation in 24-hour recalls [27-29]. The Bland-Altman plot also revealed one extreme outlier; an observation with a very high – but not biologically implausible – estimated portion size, and very low complementary food intake as reported in the 24-hour dietary recall. No other data available explains this discrepancy; the child was not underweight, wasted, or stunted; was not sick the previous day; and, according to the caregiver, had usual food intake the day before. This observation was in the partial intervention group, so social desirability bias is possible, but the caregiver reported not attending any of the community-based nutrition education meetings. Despite this, and the increasing spread of errors with increasing portion size, only 4.6% of observations fell outside the limit of agreement, and there is no evidence of systematic over- or under-estimation, as the mean difference between the two methods is only 3.5 ± 36.3 grams.

The photographs selected by caregivers correlated weakly with energy density of complementary foods; but the correlation was non-significant in several sub-groups. The photographs depict porridges, which may be difficult to relate to for caregivers who do not feed porridge, or where porridge is not the main complementary food given. While the diets lacked in diversity, only 63.8% of infants consumed any porridge; fried and baked bread products were common sources of calories. Indeed, the correlation between the consistency test indicator and the energy density of porridges specifically was somewhat stronger than average energy density of all complementary foods. The median energy density of complementary foods was 1.50 kcal/g, nearly twice the recommended minimum of 0.8 kcal/g, whereas the highest energy density of the porridge depicted in the photographs was 1.25 kcal/g. Thus, low energy dense foods was not a problem in this population, contrary to previous research in this region [18, 30, 31]. It may be useful to assess the validity of a similar indicator in a population where low energy dense complementary foods are a greater concern and/or where porridges comprise a greater proportion of complementary foods.

Each of the indicators performed well when predicting children with low energy intake from complementary foods. Estimated portion size performed approximately as well as feeding frequency. Predicting energy intake based on both estimated portion size and feeding frequency out-performed feeding frequency alone in this sample. While the consistency test indicator was a significant predictor of inadequate energy intake, it performs less well than feeding frequency, and including it in an equation predicting overall energy intake does not yield a greater area under the ROC curve. These results suggest that combining feeding frequency and portion size provide improved sensitivity and specificity for identifying children with low complementary food energy intake.

Strengths and Limitations

There are several important limitations of this research. First, the sample is of a limited age range (6 to 13 months), and results cannot be generalized to older ages. The sample is drawn from two neighboring zones in southern Ethiopia. When feeding frequency was originally validated as an indicator of energy intake from complementary foods, it was done in ten datasets from nine countries, and some heterogeneity between sites was observed [8]. Therefore, replication of these findings in other populations and older ages is important. Furthermore, no other methods of assessing portion size were tested, but other methods may yield stronger correlations or predictive power. It may be useful to develop several potential methods of estimating portion size in order to compare the validity of each.

The reference method for assessing the relative validity of these methods is the multiple-pass 24-hour dietary recall. We followed the methodology described by Gibson and Ferguson [10], including introducing caregivers to the method two to three days prior to the actual data collection. Caregivers were encouraged not to change their child's diets, but were made aware that they would be asked to estimate specific portion sizes. Even though the indicator for assessing portion size and complementary food consistency asked caregivers about their child's *usual* intake, not necessarily intake of the day before or of a specific meal, the caregivers' advanced knowledge of the multiple-pass 24-hour dietary recall may have biased these results away from the null. Furthermore, both the test methods described here and the reference method rely on caregiver recall and self-report, and are susceptible to biases. Future research should aim to validate the test methods against gold standard dietary assessments such as weighed food recall and/or doubly labeled water to estimate total energy intake within a 24-hour period.

It should also be acknowledged that the present research does not identify an optimal portion size for infants and young children. Though reducing rates of childhood undernutrition is an important goal, it should not come at the expense of promoting excessive energy intake or overriding an individual child's hunger and fullness cues. The *Guiding Principles for Complementary Feeding of the Breastfed Child* encourages caregivers to respond to a child's feeding cues when determining how much to feed [7].

Despite the limitations, there are also strengths of the research presented here. We have evaluated the relative validity of methods for assessing two complementary feeding practices for which no valid indicators have previously been established by comparing them with complementary food intake, energy intake and energy density as determined by multiple-pass 24-hour dietary recalls. We have assessed the correlations in several sub-groups, to identify circumstances in which the indicators may lack relative validity. We have also presented the correlation of feeding frequency and energy intake from complementary foods, as the standard indicator against which we evaluate methods for assessing portion size and consistency.

The test methods described and evaluated here could provide a means of assessing usual portion size and/or complementary food consistency that would not require the rigor and resources of a multiple-pass 24-hour dietary recall. In comparison, these test methods require relatively fewer materials, less training time, and place substantially less time burden on respondents; a comparison of training time, resources/materials, and respondent burden for multiple-pass 24-hour dietary recall and for the indicators described here is shown in Table 4-6.

Future Research.

The findings presented here illuminate important knowledge gaps that remain and warrant resources to address them. The validity of these indicators should be assessed among children ranging in age from 6 to 23.9 months, and in multiple low- and middle-income countries in Africa, Asia, and Latin America. Gold standard references, namely either doubly labeled water or weighed food records, should be used to establish indicator validity; these methods are more precise and do not rely on caregiver recall, thus eliminating an important source of potential bias. In validating the original WHO indicators of feeding frequency and dietary diversity, correlation coefficients were computed stratified by breastfeeding status, with some differences noted between breastfed and non-breastfed children [8, 9]. Only one of 548 infants in our sample was not breastfed, perhaps because the oldest child in our sample was 13 months old. Regardless, we were unable to examine differences by breastfeeding status. Ideally, future research should include sufficient sample size and ages to explore potential differences by breastfeeding status as well as other sub-groups, including the sub-groups explored here.

In conclusion, there was a weak overall correlation between photograph selected to represent complementary food consistency and overall energy density; this information does not contribute to identifying children with low energy intake on top of other options. It may be useful to assess this indicator in populations where low energy dense foods is of greater concern. We did establish the relative validity of caregivers' estimate of a child's usual portion size as an indicator of energy and food intake in this population, as evidenced by statistically significant correlation coefficients, and AUC greater than 0.5 for predicting children with inadequate energy intake. Combining indicators of feeding frequency and estimated portion size yielded improved identification of young children with low energy intake in this sample.

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Figure 4-1. Photographs used to assess usual complementary food consistency.

Table 4-1. Characteristics of households with infants 6 to 13 months in southern Ethiopia.

	Total (N = 548)	**6-8.9 months** (n = 121)	**9-11.9 months** (n = 310)	**12-13.9 months** (n = 117)
Age, months[1]	10.0 ± 1.7	7.5 ± 0.6	10.1 ± 0.8	12.2 ± 0.5
Female (%)	49.8	48.8	50.0	50.4
Sick yesterday (%)	18.3	19.8	19.7	12.8
Zone				
Sidama (%)	40.9	42.2	37.7	47.9
Gedeo (%)	59.1	57.9	62.3	52.1
Household fasted in previous day (%)	6.4	9.1	4.8	7.7
Caregiver education				
Less than cycle 1[2] (%)	45.2	41.2	45.8	47.9
Cycle 1 completed (%)	54.8	58.8	54.2	52.1
Child Nutritional Status				
Length-for-age z score[1]	-1.4 ± 1.2	-1.3 ± 1.3	-1.4 ± 1.2	-1.4 1.2
Stunted (%)	30.3	26.5	32.3	29.1
Weight-for-age z score[1]	-0.6 ± 1.1	-0.4 ± 1.1	-0.7 ± 1.1	-0.7 ± 1.1
Underweight (%)	11.7	8.3	13.6	10.3
Weight-for-length z score[1]	0.2 ± 1.0	0.6 ± 1.0	0.1 ± 1.0	0.0 ± 1.1
Wasted (%)	1.8	0.8	2.3	1.7
Infant and Young Child Feeding Practices[3]				
Breastfed (%)	99.8	100.0	99.7	100.0
Received solid, semi-solid, or soft foods (%)	96.2	96.7	94.8	99.2
Feeding Frequency[1]	3.6 ± 1.7	3.4 ± 1.5	3.5 ± 1.8	3.8 ± 1.7
Receive own feeding dish (%)	87.3	89.9	84.1	93.2
Consistency				
Photograph 1 (thinnest) (%)	2.4	3.6	2.2	1.8
Photograph 2 (%)	17.1	25.9	16.1	10.8

Photograph 3 (%)	65.1	58.0	66.3	69.4
Photograph 4, (%)	11.6	10.7	10.4	15.3
Photograph 5 (thickest) (%)	3.8	1.8	5.0	2.7
Portion Size, mL[4]	55 (40, 80)	50 (35, 70)	58 (40, 80)	62 (45, 80)
Estimated Nutrient Intake from Complementary Foods				
Energy intake, kcal[4]	331 (190, 490)	312 (178, 445)	323 (189, 502)	364 (240, 568)
Adequate complementary food energy intake (%)[5]	50.6	68.6	52.9	25.6
Energy density, kcal/g[4]	1.50 (1.20, 1.88)	1.51 (1.14, 1.88)	1.47 (1.20, 1.88)	1.56 (1.26, 1.87)
Adequate complementary food energy density (%)[6]	95.5	97.5	94.7	95.7

Abbreviations: mL, milliliter; kcal, kilocalorie; g, gram

[1]Values are means ± standard deviations

[2]Cycle 1 is defined as through grade 4

[3]Breastfeeding status; receipt of solid, semi-solid, or soft foods; and feeding frequency are based on recall of previous day using World Health Organization methodology [3, 4], while receipt of own feeding dish; consistency; and portion size are based on usual practice as reported by caregiver

[4]Values are median (interquartile range)

[5]Energy intakes greater than or equal to 202, 307, and 548 kilocalories for children ages 6-8.9 months, 9-11.9 months, and 12-13.9 months, respectively, are considered adequate [26]

[6]An average energy density greater than or equal to 0.8 kilocalories per gram is considered adequate

Table 4-2. Spearman rank correlation coefficients between portion size and total energy intake from complementary foods, energy intake per feeding episode, and quantity of food consumed per feeding episode.

	Total Complementary Food Energy			Complementary Food Energy per Episode			Complementary Food Weight per Episode		
	n	rho	p_{diff}[1]	n	rho	p_{diff}	n	rho	p_{diff}
Total	541	0.42***	-	539	0.45***	-	539	0.44***	-
Child had solid/semi-solid/soft foods	525	0.45***	-	523	0.48***	-	523	0.46***	-
6-8.9 months	118	0.47***		117	0.54***		117	0.53***	
9-11.9 months	306	0.39***		305	0.39***		305	0.41***	
12-13.9 months	117	0.43***		117	0.53***		117	0.43***	
Receive own dish	472	0.42***		470	0.46***		470	0.45***	
Eats from shared plate	69	0.36**		69	0.36**		69	0.38**	
Control	229	0.41***		227	0.39***	Control vs Full: *	227	0.46***	Control vs Partial: *
Partial Intervention	142	0.29***	Partial vs Full: *	142	0.34***	Partial vs Full: **	142	0.28***	Partial vs Full: *
Full Intervention	170	0.50***		170	0.61***		170	0.52***	
Sidama zone	223	0.46***		223	0.54***	*	223	0.49***	
Gedeo zone	318	0.39***		316	0.38***		316	0.42***	
Not sick yesterday	442	0.48***	**	440	0.50***	**	440	0.46***	
Sick yesterday	98	0.15		98	0.22*		98	0.36***	
Household did not fast yesterday	506	0.41***		504	0.45***		504	0.43***	
Household fasted yesterday	35	0.46**		35	0.41*		35	0.66***	
Caregiver did not complete cycle 1[2]	243	0.45***		243	0.47***		243	0.46***	
Caregiver did complete cycle 1	296	0.39***		294	0.43***		294	0.42***	

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

[1]p_{diff} = based on Fisher r-to-z-transformation

[2]Cycle 1 is grades 1 through 4

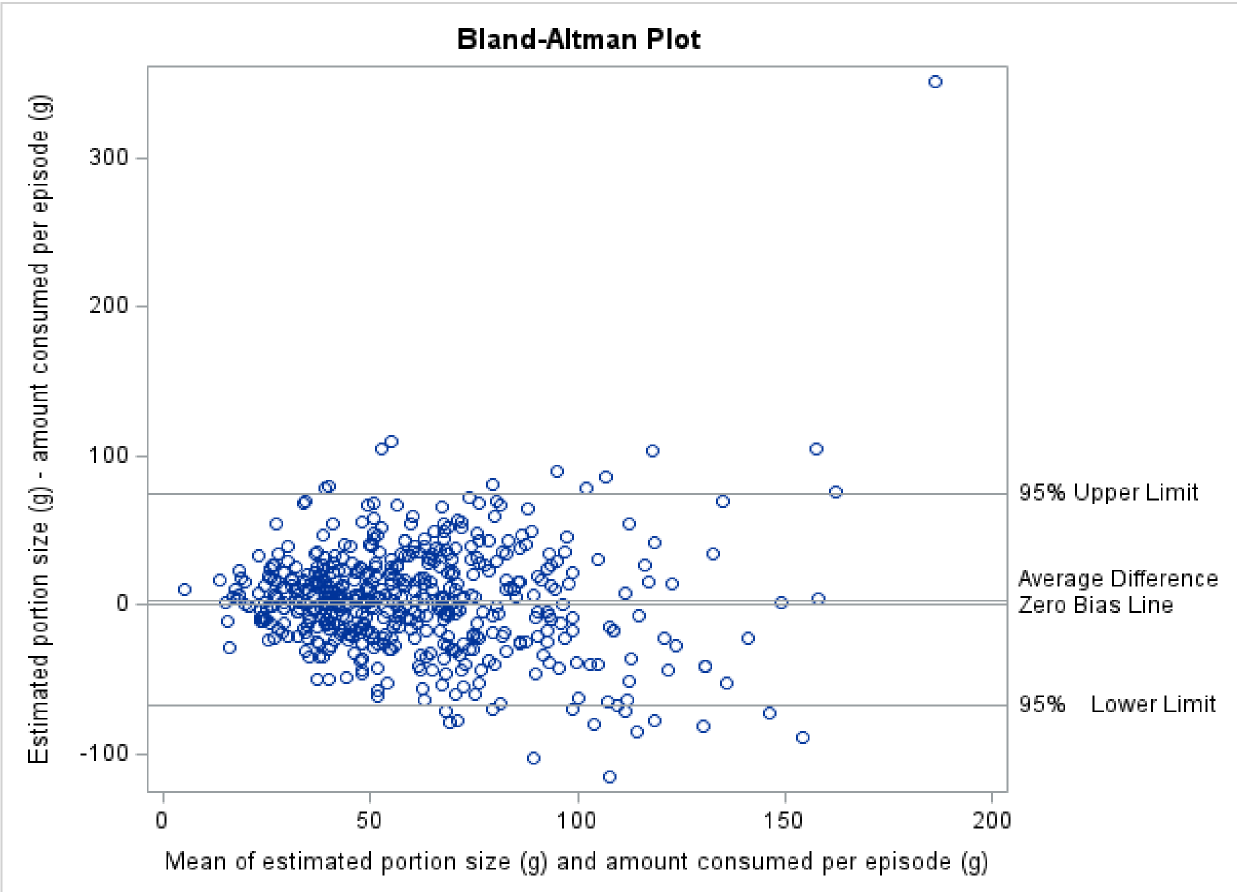

Figure 4-2. Bland-Altman plot showing agreement between estimated portion size and amount of food consumed per episode.

Table 4-3. Spearman rank correlation coefficients between feeding frequency and total energy intake from complementary foods.

	n	rho		p_{diff}[1]
Total	545	0.41	***	-
Child had solid, semi-solid, or soft foods	524	0.37	***	-
6-8.9 months	120	0.27	**	
9-11.9 months	309	0.45	***	
12-13.9 months	116	0.44	***	
Receive own dish	472	0.41	***	
Eat from shared dish	69	0.19		
Control	233	0.33	***	
Partial Intervention	143	0.50	***	
Full Intervention	169	0.45	***	
Sidama	224	0.46	***	*
Gedeo	321	0.30	***	
Not sick yesterday	445	0.35	***	**
Sick yesterday	99	0.58	***	
Household did not fast yesterday	511	0.42	***	
Household fasted yesterday	34	0.39	*	
Caregiver did not complete cycle 1[2]	245	0.38	***	
Caregiver did complete cycle 1	298	0.42	***	

* p<0.05; ** p<0.01; ***p<0.001

[1]p_{diff} = based on Fisher r-to-z-transformation

[2]Cycle 1 is grades 1 through 4

Table 4-4. Polyserial correlation coefficients between complementary food consistency and energy density.

	Average energy density of all complementary foods				Average energy density of porridges/gruels only			
	n	rho		p_{diff}[1]	n	rho		p_{diff}
Total	495	0.10	*		349	0.24	***	
Child consumed solid, semi-solid, or soft foods	489	0.10	*		348	0.24	***	
6-8.9 months	111	0.05			93	0.08		
9-11.9 months	273	0.12			184	0.30	***	
12-13.9 months	111	0.12			72	0.14		
Eat from shared dish	451	0.09			325	0.23	***	
Receive own dish	44	0.17			24	0.29		
Control	198	0.12			133	0.27	**	
Partial Intervention	133	0.18	*		93	0.31	**	
Full Intervention	164	-0.03			123	0.12		
Sidama	220	0.10			183	0.28	***	
Gedeo	275	0.18	**		166	0.23	**	
Not sick yesterday	411	0.07			296	0.21	***	
Sick yesterday	83	0.28	*		52	0.37	**	
Household did not fast yesterday	463	0.10			330	0.23	***	
Household fasted yesterday	32	0.16			19	0.20		
Caregiver did not complete cycle 1[2]	218	0.18	*		146	0.35	***	
Caregiver did complete cycle 1	276	0.06			203	0.16	*	

* $p<0.05$; ** $p<0.01$; ***$p<0.001$

[1]p_{diff} = based on Fisher r-to-z-transformation

[2]Cycle 1 is grades 1 through 4

Table 4-5. Areas under Receiver Operating Characteristic curves predicting young predicting low energy intake among children ages 6-8.9 months, 9-11.9 months, and 12-13.9 months.

	AUC	95% CI	Contrast[1]	95% CI
6-8.9 months				
Feeding Frequency	0.61	0.50, 0.73	Ref.	Ref.
Consistency	0.63	0.53, 0.73	0.02	-0.14, 0.18
Portion Size	0.74	0.64, 0.85	0.13	-0.05, 0.31
Predicted Energy Intake$_2$[2]	0.80	0.71, 0.89	0.19	0.07, 0.31
Predicted Energy Intake$_3$[3]	0.81	0.72, 0.91	0.20	0.08, 0.32
9-11.9 months				
Feeding Frequency	0.69	0.63, 0.75	Ref.	Ref.
Consistency	0.57	0.51, 0.62	-0.12	-0.20, -0.04
Portion Size	0.67	0.61, 0.74	-0.02	-0.11, 0.08
Predicted Energy Intake$_2$	0.77	0.72, 0.83	0.09	0.03, 0.14
Predicted Energy Intake$_3$	0.76	0.70, 0.81	0.07	0.01, 0.13
12-13.9 months				
Feeding Frequency	0.80	0.72, 0.89	Ref.	Ref.
Consistency	0.59	0.50, 0.67	-0.22	-0.33, -0.10
Portion Size	0.72	0.62, 0.82	-0.09	-0.22, 0.05
Predicted Energy Intake$_2$	0.84	0.77, 0.92	0.04	-0.03, 0.11
Predicted Energy Intake$_3$	0.85	0.78, 0.92	0.05	-0.02, 0.12

Abbreviations: AUC, area under the curve; CI, confidence interval; Ref, Reference

[1]Contrast represents difference in AUC

[2]Predicted Energy Intake$_2$ = feeding frequency x portion size, assumes food density of 1.05 grams/milliliter and an energy density of 1 kilocalorie/gram

[3]Predicted Energy Intake$_3$ = feeding frequency x portion size x energy density of consistency test indicator, assumes food density of 1.05 grams/milliliter

Table 4-6. Comparison of resources required for multiple-pass 24-hour dietary recall and proposed indicators of portion size and complementary feeding.

	Multiple-pass 24-hour dietary recall	**Test indicators**
Training	10 days enumerator training	1/2 day enumerator training
	2 day pilot test	1/2 day pilot test
	1 day re-training	
Mother Training	20 days, 4 enumerators	Not applicable
	1 bowl per respondent	
	Refreshments	
	1 Food picture chart (color printed) per respondent	
	1 Pencil per respondent	
Supplies	Questionnaire (4-6 pages)	Questionnaire (<1 page)
	Backpack, clipboard, pens/pencils	Backpack, clipboard, pens/pencils
	Bowls	Bowls
	Graduated cylinders	Graduated cylinders
	Uncooked rice (2 kg)	Uncooked rice (1 kg)
	Food photographs	Printed consistency photographs
	Playdough	
	Scales	
	Utensils (spoons, knife)	
	Cups	
	Pot/pan	
	Spare batteries	
	Lists of probing questions and measurement methods	
Respondent Burden	Roundtrip travel to "mother training" (time varies)	5-10 minutes in household interview
	30-60 minutes at "mother training"	
	45-75 minutes per household interview	

Supplemental Table 4-1. Spearman rank correlation coefficients between portion size and total energy intake from complementary foods, energy intake per feeding episode, and quantity of food consumed per feeding episode, among children who consumed complementary foods or liquids

	Total Complementary Food Energy				**Complementary Food Energy per Episode**				**Complementary Food Weight per Episode**			
	n	**rho**		**p_{diff}**[1]	**n**	**rho**		**p_{diff}**	**n**	**rho**		**p_{diff}**
Total	533	0.44	***	-	531	0.48	***	-	531	0.47	***	-
Child had solid/semi-solid/soft foods	525	0.45	***	-	523	0.48	***	-	523	0.46	***	-
6-8.9 months	117	0.48	***		116	0.56	***		116	0.54	***	
9-11.9 months	299	0.43	***		298	0.43	***		298	0.45	***	
12-13.9 months	117	0.43	***		117	0.53	***		117	0.43	***	
Receive own dish	466	0.44	***		464	0.52	***		464	0.47	***	
Eats from shared plate	67	0.44	***		67	0.47	***		67	0.46	***	
Control	222	0.47	***		220	0.45	***		220	0.52	***	
Partial Intervention	141	0.31	***		141	0.36	***	*	141	0.29	***	
Full Intervention	170	0.50	***	*	170	0.61	***	**	170	0.52	***	*
Sidama zone	223	0.46	***		223	0.54	***		223	0.49	***	
Gedeo zone	310	0.43	***		308	0.43	***		308	0.47	***	
Not sick yesterday	442	0.48	***		440	0.50	***		440	0.46	***	
Sick yesterday	90	0.27	**	*	90	0.35	***		90	0.51	***	
Household did not fast yesterday	498	0.44	***									
Household fasted yesterday	35	0.46	**									
Caregiver did not complete cycle 1[2]	240	0.45	***		240	0.47	***		240	0.46	***	
Caregiver did complete cycle 1	291	0.44	***		289	0.48	***		289	0.47	***	

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

[1]p_{diff} = based on Fisher r-to-z-transformation

[2]Cycle 1 is grades 1 through 4

Supplemental Table 4-2. Spearman rank correlation coefficients between feeding frequency and total energy intake from complementary foods, among children who consumed complementary foods or liquids.

	n	rho		p_{diff}[1]
Total	534	0.38	***	-
Child had solid, semi-solid, or soft foods	524	0.37	***	-
6-8.9 months	117	0.21	*	
9-11.9 months	301	0.41	***	
12-13.9 months	116	0.44	***	
Receive own dish	466	0.38	***	* (Receive own dish vs. Eat from shared dish)
Eat from shared dish	67	0.11		
Control	223	0.24	***	** (Control vs. Partial Intervention); * (Control vs. Full Intervention)
Partial Intervention	142	0.48	***	
Full Intervention	169	0.45	***	
Sidama	224	0.46	***	** (Sidama vs. Gedeo)
Gedeo	310	0.22	***	
Not sick yesterday	443	0.34	***	
Sick yesterday	90	0.44	***	
Household did not fast yesterday	500	0.38	***	
Household fasted yesterday	34	0.39	*	
Caregiver did not complete cycle 1[2]	241	0.35	***	
Caregiver did complete cycle 1	291	0.38	***	

* p<0.05; ** p<0.01; ***p<0.001

[1]p_{diff} = based on Fisher r-to-z-transformation

[2]Cycle 1 is grades 1 through 4

Supplemental Table 4-3. Area under Receiver Operating Characteristic curves predicting low energy intake among young children ages 6-8.9 months, 9-11.9 months, and 12-13.9 who consumed complementary foods or liquids.

	AUC	95% CI	Contrast[1]	95% CI
6-8.9 months				
Feeding Frequency	0.60	0.48, 0.72	Ref.	Ref.
Consistency	0.63	0.52, 0.73	0.02	-0.14, 0.18
Portion Size	0.75	0.64, 0.85	0.15	-0.03, 0.33
Predicted Energy Intake$_2$[2]	0.80	0.70, 0.89	0.20	0.08, 0.31
Predicted Energy Intake$_3$[3]	0.81	0.71, 0.91	0.21	0.08, 0.33
9-11.9 months				
Feeding Frequency	0.67	0.61, 0.73	Ref.	Ref.
Consistency	0.57	0.51, 0.62	-0.11	-0.19, -0.02
Portion Size	0.69	0.62, 0.75	0.01	-0.08, 0.10
Predicted Energy Intake$_2$	0.76	0.71, 0.82	0.09	0.03, 0.15
Predicted Energy Intake$_3$	0.74	0.68, 0.80	0.07	0.01, 0.13
12-13.9 months				
Feeding Frequency	0.80	0.72, 0.89	Ref.	Ref.
Consistency	0.59	0.51, 0.67	-0.22	-0.33, -0.10
Portion Size	0.72	0.62, 0.82	-0.09	-0.22, 0.05
Predicted Energy Intake$_2$	0.84	0.77, 0.92	0.04	-0.03, 0.11
Predicted Energy Intake$_3$	0.85	0.78, 0.92	0.05	-0.02, 0.12

Abbreviations: AUC, area under the curve; CI, confidence interval; Ref, Reference

[1]Contrast represents difference in AUC

[2]Predicted Energy Intake$_2$ = feeding frequency x portion size, assumes food density of 1.05 grams/milliliter and an energy density of 1 kilocalorie/gram

[3]Predicted Energy Intake$_3$ = feeding frequency x portion size x energy density of consistency test indicator, assumes food density of 1.05 grams/milliliter

Chapter 5 - Complementary feeding patterns in rural Malawi

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Abstract

Background. Complementary feeding is multi-dimensional, but methods for assessing complementary feeding largely fail to capture this multi-dimensionality.

Objective. The objective of the present research is to apply exploratory factor analysis (EFA) to individual complementary feeding indicators to identify complementary feeding patterns, and to use exploratory structural equation modeling (ESEM) to identify complementary feeding predictors.

Methods. We use data from 1,325 households in Mchinji, Malawi with infants and young children. Caregivers completed a survey that assessed household sociodemographic characteristics, and complementary feeding practices, including standard World Health Organization indicators of infant and young child feeding. We also assessed usual portion size and complementary food consistency. We used EFA to identify patterns of complementary feeding practices, and evaluated model fit with standard fit indices (chi-square statistic, root mean square error of approximately, Tucker-Lewis Index, and Comparative Fit Index). We used ESEM to regress latent factors onto potential predictors of complementary feeding. The analyses were done separately for the following age groups: children 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months.

Results. Acceptable model fit was achieved in each age group with two-factor solutions. Though patterns and factor loadings differed by age group, there were similarities. Protein-rich food groups (meat, eggs, dairy, and plant protein) loaded onto the first factor. Minimum meal frequency, vitamin A-rich fruits and vegetables, other fruits and vegetables, thick complementary foods, and portion size tended to load onto a second factor. The food group indicator for staples was inconsistent between ages. Traditional Authority, the term for sub-districts, was the

strongest and most consistent predictor associated with complementary feeding; household wealth and food insecurity were also associated with complementary feeding in more than one age group. Other predictors that were inconsistently associated with complementary feeding included child age, whether or not the child received his or her own dish, caregiver education, and whether or not the caregiver is the household head.

Conclusion. Complementary feeding practices were correlated. Predictors related to food access and availability were consistently associated with complementary feeding.

5.1 Introduction

Complementary feeding is the process of introducing and feeding non-breastmilk (or non-breastmilk substitute) foods and liquids. Complementary foods are recommended at 6 months, when breastmilk alone is no longer sufficient to support optimal growth and development, and extends until 24 months [1]. The *Guiding Principles for Complementary Feeding of the Breastfed Child* should serve as the basis of formulating recommendations and developing behavior change strategies in low- and middle-income countries. The *Guiding Principles* encompass several domains of complementary feeding, including quantity and quality of food, responsive feeding and hygienic food preparation [1].

Based on the *Guiding Principles*, the World Health Organization (WHO) developed a set of eight core and seven optional indicators of infant and young child feeding (IYCF) and a guide to their use [2, 3]. The indicators offer a standardized approach to assessing select IYCF practices that are amenable to large, community-based surveys where in-home observations or rigorous dietary assessment is too cumbersome. The validity of minimum feeding frequency and dietary diversity have previously been assessed [4, 5]. The indicators should be considered as a whole "because of the multi-dimensional aspects of appropriate feeding" [2]. However, researchers interested in predictors or outcomes of IYCF have typically employed "association research…separately for each indicator"; association studies where individual indicators are considered in isolation may not be meaningful [6].

Minimum acceptable diet is a dichotomous indicator that incorporates current breastfeeding status, minimum meal frequency, and minimum dietary diversity. Others have tabulated summary indices – incorporating current breastfeeding, bottle use, meal frequency, dietary diversity in previous 24 hours, and/or food group frequency in previous 7 days – which have been used to investigate predictors and outcomes of appropriate IYCF practices [7-11]. An important limitation of these indices, however, is that they assume feeding practices are equally weighted [7].

Factor analysis and principal component analysis have been used to characterize dietary patterns in diverse populations, typically using dietary recall or food frequency data [12, 13]. Dietary pattern analysis allows researchers to examine associations with potential predictors and/or health- or disease-related outcomes of overall diet patterns. A number of studies have looked at dietary patterns in infants and young children in high-income countries using dietary recall data [14-20]. To our knowledge, however, factor analysis has never been applied to IYCF indicators.

Factor analysis is a method of extracting latent factor(s) to summarize correlations between a series of indicator variables. Confirmatory factor analysis (CFA) is carried out to confirm a previously-hypothesized factor structure, while exploratory factor analysis (EFA) is an initial step taken when there is no preexisting hypothesis about factor structure. The result of a CFA or EFA is a measurement model that describes the relationships between factors and their indicators. In CFA, factor indicators are typically permitted to load onto one factor, while cross-loadings onto other factors are restricted to zero. In EFA, cross-loadings are freely estimated. In exploratory structural equation modeling (ESEM), associations between the latent factors resulting from EFA and potential predictors or outcomes can be assessed without restricting cross-loadings to zero, which can otherwise bias estimates [21, 22]. Models in which one or more latent factors are regressed onto predictor variables, also known as a Multiple-Indicators, Multiple-Causes models, are multivariate linear models.

The aim of this research is to conduct EFA on a set of IYCF indicators – including WHO indicators as well as indicators of portion size and complementary food consistency – and to explore the cross-sectional association between complementary feeding and potential predictors using ESEM.

5.2 Methods

5.2.1 Study Setting and Population

The analyses presented here are secondary analyses using data from longitudinal operations research in rural Malawi; the primary aim of the operations research was to evaluate the impact of a nutrition-specific intervention promoting improved IYCF implemented by Concern Worldwide. In 2015, Concern Worldwide operated Care Groups in 3 Traditional Authorities (TAs; a TA is a type of administrative region) in the Mchinji District in central Malawi; Care Groups serve as a model for disseminating health and nutrition education to households with pregnant women and/or young children [23]. Care Groups were randomly selected to participate in an operations research study on child feeding, and were subsequently randomized to receive either the standard of care, or an enhanced intervention including novel behavior change tools for optimal IYCF practices. The data used in these analyses come from a baseline survey that was conducted prior to intervention delivery. Sixty Care Groups were randomly selected for a target sample size of 1,300 households for the evaluation. Convenience samples were drawn from each Care Group, but data collection stopped after sampling from 51 Care Groups because the desired sample size had been surpassed. In subsequent data cleaning, it was discovered that households from two additional Care Groups were included in the sample. Thus, the data analyzed here include 53 clusters.

Households were eligible to participate if they had a child between 6 to 17.9 months of age, and if the primary caregiver was available and consented to participate. Consent was obtained from Care Group leaders as well as from individual caregivers.

5.2.2 Data Collection

The data were collected in July and August of 2015 under the supervision of Concern Worldwide. The survey collected data on household sociodemographic characteristics including ownership of durable goods; access to water and sanitation facilities; nutrition knowledge; IYCF practices; and anthropometric measurements. Standard WHO indicators of meal frequency, dietary diversity, breastfeeding status, and bottle use were collected based on recall of the previous day [2, 3].

In addition, we developed and included an assessment of portion size and complementary food consistency. For portion size, caregivers were first asked whether their child most often receives his/her own dish or shares with other family member(s). If the child received his or her own dish, caregivers were guided to use uncooked rice to estimate the usual portion served, and the portion leftover (if any). These volumes of uncooked rice were transferred to a measurement cylinder and the volume recorded to the nearest 10 milliliter (mL); an estimate of the usual volume consumed was calculated by subtracting volume leftover from volume served. If the child shared a feeding dish then caregivers were asked to estimate the volume that the child consumed using the uncooked rice, which was also measured to the nearest 10 mL. Complementary food consistency was assessed by showing caregivers five photographs of porridges of increasing thickness; caregivers were asked to select which one most closely resembled his or her child’s usual complementary food. The first two photographs corresponded to complementary foods that are less than 0.8 kilocalories per gram (kcal/g), which is the recommended minimum energy density for complementary foods [1]. The third photograph has an energy density of approximately 0.8 kcal/g, while the fourth and fifth photographs have energy densities of more than 0.8 kcal/g.

5.2.3 Variable Specification

A wealth index was computed using principal component analysis to derive weights for indicator variables; indicator variables included ownership of durable goods, source of primary drinking water, and access to sanitation facilities. The resulting index was classified by tercile, such that the lowest tercile represents poorer households and the highest tercile represents wealthier households according to the index. Household food insecurity was measured via the Household Food Insecurity Access Scale [24].

Using estimated portions consumed, we derived quintiles for portion size that were age-group specific (for 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months). Complementary food consistency was classified as either thin (photographs 1 and 2) or thick (photographs 3, 4, and 5).

5.2.4 Analytical Approach

In preliminary analysis applying CFA with one general factor, we observed measurement non-invariance between age groups (6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months) and a rejection of the hypothesized one-factor structure. Therefore, for the analyses presented here, we treat each age group separately, and apply exploratory, rather than confirmatory, procedures, namely EFA and ESEM.

The indicators used in these analyses included breastfeeding, bottle use, minimum meal frequency, and individual food group indicators for the seven food groups making up the child dietary diversity score; all of the aforementioned indicators were based on recall of the previous day as per WHO methodology [2, 3] and were dichotomous (yes/no). In addition, we included a binary indicator for complementary food consistency, and a 5-category ordinal indicator of usual portion size quintile. Thus, there were 12 possible complementary feeding indicators.

Appropriateness of the data for EFA was first assessed by examining correlations among all indicators, and by the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) and Bartlett's Test of Sphericity. For KMO-MSA, values less than 0.5 are considered inappropriate for factor analysis; values greater than 0.5 are considered appropriate, but closer to 1 are better [25]. For Bartlett's test of Sphericity; a significant p-value (<0.05) indicates acceptability of factor analysis [26].

We first conducted EFA on a set of complementary feeding indicators in each age group. If an indicator had very little variation and resulted in an empty bivariate cell with another indicator, then that indicator was dropped. We used the weighted least squares means and variance adjusted (WLSMV) estimator, which is considered appropriate for categorical factor indicators [27], and a Geomin rotation which is an oblique rotation that allows factors to correlate [27]. We chose a Geomin rotation due to the theoretical possibility of correlated factors and so that we could evaluate the potential correlation; if the correlation was weak (<0.3), then an orthogonal rotation – in which factors are uncorrelated – was considered.

The optimal number of factors to be extracted was evaluated based on visual inspection of scree plots, theoretical justification, and model fitness based on the following: chi-square test of model fit, root mean square error of approximation (RMSEA), the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Standardized Root Mean Square Residual (SRMR). The following thresholds were considered for assessing goodness-of-fit: chi-square p-value <0.05, CFI $\geq$0.95, TLI $\geq$0.90, RMSEA <0.05, and SRMR <0.08 [28]. The most parsimonious factor structure that gave a reasonable fit was selected.

Once the ideal number of factors had been determined for each age group, we regressed the factors onto a series of potential predictors using ESEM. The potential predictors tested included age, sex, TA, household food insecurity, wealth tercile, and binary variables to indicate the following: whether the caregiver is the household head, whether the caregiver completed primary school, whether the child receives or is fed from his/her own dish, and whether the child had diarrhea in the previous day.

Data cleaning, variable specification, and descriptive statistics were run in SAS 9.4 (SAS Institute, Cary, NC, USA); EFA and ESEM were conducted in Mplus version 7.4 (Muthen and Muthen, Los Angeles, CA, USA). Standard errors were adjusted for clustering of Care Groups using the cluster option in Mplus [27].

5.2.5 Ethical approval

Ethical approval for data collection was provided by Malawi's National Health Sciences Research Committee. Emory University Institutional Review Board deemed Emory researchers exempt from ethical review for data collection, but approved procedures for data cleaning and management. The analyses described here are secondary data analyses.

5.3 Results

A total of 1,368 households with young children consented to and participated in the survey. Of this total, 43 were excluded for the following reasons: 28 did not meet eligibility criteria (14 children had serious health problems, in 4 cases the primary caregiver was unavailable to complete the survey, and in 10 cases the child was either too young or too old); 13

were missing data on Care Group membership (the clustering variable); and two were missing date of birth. The resulting sample eligible for analysis was 1,325: 371 for the 6 to 8.9 month age group, 404 for the 9 to 11.9 month age group, and 550 for the 12 to 17.9 month age group.

Characteristics of the analytical sample are shown in Table 5-1. Just below half of the sample (45.1%) lived in Mkanda TA; 34.9% lived in the Mduwa TA and 20.0% lived in the Zulu TA. There was a high prevalence of moderate (15.9%) or severe (56.3%) food insecurity. The child's caregiver was also the head of household in 5.6% of households, and only 17.4% of caregivers had completed primary school. Just below half (48.8%) of caregivers had no employment outside the home, while 48.2% of caregivers worked in agriculture, domestic work, or unskilled manual labor; 3.1% of caregivers had professional or skilled manual work.

In the previous day, almost all children (97.3%) were breastfed, and only 4.0% were fed anything with a bottle. Among infants 6 to 8.9 months, approximately two-thirds met the minimum meal frequency for their age (2 meals per day); only 41.9% and 43.1% of infants 9 to 11.9 months and children 12 to 17.9 months, respectively met minimum meal frequency for their age (3 meals per day). Staples were the most commonly consumed food group (86.5%), followed by vitamin A-rich fruits and vegetables (68.9%). No other food group was consumed by more than one-third of the sample. With the exception of staples and dairy, older children were more likely to consume each food group. A majority (84.5%) of the children received their own feeding dish for meals. Nearly three-quarters (74.5%) of the sample received thick complementary foods, but this practice was less common among infants 6 to 8.9 months (60.5%) than among infants 9 to 11.9 months (76.9%) or children 12 to 17.9 months (82.2%). The median and interquartile range (IQR) for usual portion sizes were 89 (46, 104) mL, 97 (57, 140) mL, and

108 (88, 155) mL for children 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months, respectively.

Breastfeeding and bottle use in the previous day were dropped as factor indicators, as they had too little variability, resulting in empty bivariate cells in each age group. The KMO-MSA statistic was 0.727, 0.666, and 0.706 for 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months, respectively. Bartlett's Test of Sphericity was $p<0.0001$ for all age groups. Together, these findings supported proceeding with factor analysis.

In each individual age group, two-factor solutions were identified with correlated factors (factor correlations = 0.44, 0.39, and 0.32 among ages 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months, respectively, all $p<0.05$), though the patterns and magnitudes of factor loadings differed by age group. Factor loadings and their confidence intervals are displayed in Figure 5-1; factor loadings and model fit are shown in Table 5-2.

Among infants 6 to 8.9 months, protein-rich food group indicators (meat, eggs, plant protein, and dairy) loaded onto the first factor. Indicators of staple food consumption, vitamin A-rich fruits and vegetable consumption, and other fruits and vegetable consumption, thick complementary foods, minimum meal frequency, and portion size all loaded onto the second factor. The model fit the data well (chi-square p-value=0.08; RMSEA=0.034; CFI=0.968; TLI=0.945; SRMR=0.064). The pattern among infants 9 to 11.9 months was similar to their younger counterparts, with the difference being that the staple food group indicator loaded onto the first factor with protein-rich food groups, rather than onto the second factor. The model had good fit (chi-square p-value=0.09; RMSEA=0.031; CFI=0.965; TLI=0.940; SRMR=0.067). Among children over one year old, neither complementary food thickness nor portion size had significant factor loadings for either factor, leaving only the food group indicators and minimum meal frequency. The first factor had significant factor loadings for the protein-rich food group indicators, as well as for other fruits and vegetables, and minimum meal frequency. The second factor had significant factor loadings for staples, vitamin A-rich and other fruits and vegetables, and minimum meal frequency. In this age group, other fruits and vegetables and minimum meal frequency loaded onto both factors. The model had acceptable fit (chi-square p-value=0.04; RMSEA=0.031; CFI=0.955; TLI=0.921; SRMR=0.062).

Results of the ESEM models are shown in Table 5-3. With Mduwa acting as the reference TA, in each age group, Factor 1 was significantly and positively associated with the TA Zulu; Factor 1 was also positively associated with the Mkanda TA, though the parameter was not significant in the youngest age group. Factor 1 was also negatively associated with food insecurity, though not significantly so among children over 1 year of age. Similarly, Factor 1 was positively associated with wealth among children 9 to 11.9 months and 12 to 17.9 months. Factor 1 was positively associated with a child receiving his or her own dish only in the youngest age group, and with age among children over 1 year.

Factor 2 was not associated with any individual predictor in more than one age group. It was positively associated with age in the youngest children, with caregiver education in the oldest age group, and negatively associated with food insecurity among children 9 to 11.9 months of age.

5.4 Discussion

We have demonstrated that individual complementary feeding indicators – including food group indicators, minimum meal frequency, complementary food thickness, and portion size – are intercorrelated and appropriate for factor analysis. In each age group, a two-factor model was identified that fit the data well. None of the significant factor loadings were negative, confirming that positive practices clustered in this sample, and that caregivers do not compensate, for example by increasing portion sizes for infrequent meals.

There were similarities in the factor structures of each age group. In each age group, protein-rich foods all loaded onto the first factor. The second factor is more difficult to interpret. Vitamin A-rich fruits and vegetables and other fruits and vegetables were correlated and loaded onto the second factor, as did minimum meal frequency. Complementary food thickness and portion size loaded onto the second factor only among infants under one year, and the magnitude of the factor loading is greatest among infants under 9 months. This could reflect the increasing proportion of children receiving thick complementary foods in each successive age group, such that 82.2% of children over one year received thick complementary foods. This could also reflect the fact that portion size and complementary food thickness indicators inquired about usual practices, while the other indicators are specific to the previous day.

In early analysis we included a more detailed list of 17 food types in the EFA rather than the seven food groups used in the child dietary diversity indicator [3], in addition to indicators of meal frequency, complementary food thickness, and portion size; those results, however, had poor fit and/or were uninterpretable. Dietary pattern analysis using dietary data collected through 24-hour recall or weighed food records may be more informative about food consumption patterns, but would fail to account for other facets of complementary feeding, namely feeding frequency, portion size, and consistency. Future research could assess relationships between dietary patterns and other complementary feeding indicators.

Staples alternated somewhat between factors 1 and 2 depending on the age group. Staples were the most commonly consumed food group, with over 85% of children in each age group having consumed this food group. Similarly, Cabral *et al.* applied EFA to food consumption frequency among Cape Verdeans and found that rice, which was consumed by 83.1% of their sample, did not load onto any factors [12].

The only sociodemographic predictor associated with any latent factor in all age groups was TA, where Factor 1 scores were highest in the Zulu and Mkanda TAs. The reasons for this association are unclear, but TA could indicate influences such as food and market access, farming or livestock practices, exposure to mass media or health services, or socioeconomic status. Unfortunately, no more nuanced indicators exist for most of these potential predictors with which we could test this hypothesis. Food insecurity was negatively associated with Factor 1, and with Factor 2 among infants 9 to 11.9 months. Being in the wealthiest tercile, compared to the least wealthy, was positively associated with Factor 1 among children 9 months and older; the estimate among the youngest age group was not significant though there may be a trend. Consistent with our finding, Nkoka *et al.* found that children from wealthier households, had improved dietary diversity, however, they also found that children whose caregiver(s) had higher education and older children had improved dietary diversity [29], findings not replicated in our results. Surprisingly, no other predictor was consistently associated with either factor in multiple age groups. These results suggest that issues related to food access or affordability may be the strongest predictor of complementary feeding practices. Bazzano *et a.l* conducted a review of qualitative literature identify barriers and facilitators to recommended complementary feeding and concluded with high confidence that food insecurity and shortages were barriers to complementary feeding [30]. Gewa *et al* reviewed national survey data from three East African countries and found increased wealth to be associated with improved dietary diversity in each; interestingly, the only other two variable associated with meeting dietary diversity in each of the three countries were child age and whether or not the child had met minimum meal frequency [31].

There are several limitations of this research. First, while conducting EFA and ESEM separately for each age group allows us to compare differences in factor structure between the groups, it also limits our sample size and therefore may limit our statistical power to detect relationships between the factors and sociodemographic predictors. Furthermore, the age strata result in fairly narrow age bands which may limit our ability to identify the relationship between age and complementary feeding. The approach described does not weight indicators' importance, and we have not assessed whether any of the factors are associated with health- or nutrition-related outcomes. The data used in this analysis are cross-sectional, and therefore we cannot establish causality between sociodemographic variables and complementary feeding. While we are interested in portion size, we are unable to apply any adjustment to food group indicators based on energy intake, and we acknowledge that this would be ideal. Lastly, the results presented here are not intended to be generalizable to other samples; the most consistent predictor of complementary feeding in this sample was the TA which, by nature, is specific to the region.

An important strength of these analyses is the demonstration, through the KMO-MSA, Bartlett's Test of Sphericity, and fit of the EFA, that factor analysis is an appropriate and feasible approach for complementary feeding indicators. We have also applied ESEM to identify potential predictors, which may be more meaningful than examining the associations with individual feeding practices.

In conclusion, complementary feeding practices co-vary. In this sample of infants and young children ages 6 to 17.9 months in rural Malawi, protein-rich food groups correlate, while indicators of fruit and vegetable intake and meal frequency correlate. Relationships to portion size and consistency are less clear, but there is evidence that they are also correlated. Predictors related to food access and availability are the strongest and most consistently associated with overall complementary feeding, suggesting that these environmental determinants play a strong role in complementary feeding behaviors. Quantitative methods that account for the covariance of complementary feeding indicators will be more informative and appropriate for epidemiological research on complementary feeding.

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Table 5-1. Characteristics of households with young children ages 6 to 17.9 months in Mchinji, Malawi.

	Total N=1325	**6-8.9 months** n = 371	**9-11.9 months** n = 404	**12-17.9 months** n = 550
Socio-Demographic Characteristics				
Traditional Authority				
Zulu (%)	20.0	23.5	18.8	18.6
Mkanda (%)	45.1	42.6	46.8	45.5
Mduwa (%)	34.9	34.0	34.4	36.0
Wealth Index				
Lowest tercile, (%)	34.0	32.9	35.4	33.7
Middle tercile (%)	31.7	29.9	30.9	33.5
Highest tercile (%)	34.3	37.2	33.7	32.8
Household food security status[1]				
Food secure (%)	14.8	15.1	14.6	14.7
Mildly food insecure (%)	13.0	12.4	14.6	12.1
Moderately food insecure (%)	15.9	16.2	14.4	16.9
Severely food insecure (%)	56.3	56.3	56.4	56.3
Caregiver is household head (%)	5.6	6.2	5.5	5.3
Caregiver has completed primary school (%)	17.4	18.1	17.6	16.7
Caregiver occupation				
None (%)	48.8	49.3	47.3	49.5
Professional or skilled manual labor (%)	3.1	4.6	2.5	2.6
Agriculture or unskilled manual labor (%)	48.2	46.1	50.3	48.0
Age, months[2]	10.8 ± 3.2	6.9 ± 0.8	10.0 ± 0.8	14.1 ± 1.5
Female (%)	48.3	45.1	49.0	49.9
Nutritional Status				
Length-for-age z score[2]	-1.3 ± 1.4	-1.2 ± 1.3	-1.3 ± 1.4	-1.4 ± 1.4
Stunted (%)	29.5	23.4	29.3	33.8
Weight-for-age z score[2]	-0.6 ± 1.2	-0.5 ± 1.2	-0.6 ± 1.1	-0.7 ± 1.2

Underweight (%)	11.4	9.8	11.1	12.7
Weight-for-length z score[2]	0.1 ± 1.3	0.3 ± 1.4	0.1 ± 1.2	-0.1 ± 1.2
Wasted (%)	4.7	4.1	3.5	6.1
Infant and Young Child Feeding				
BF Yesterday[3] (%)	97.3	99.7	98.5	94.8
Use bottle[3] (%)	4.5	4.3	5.2	4.0
Minimum Meal Frequency[3] (%)	49.4	66.8	41.9	43.1
Food Groups[3]				
Staples (%)	86.5	89.8	85.2	85.3
Plant Protein (%)	31.3	27.0	33.7	32.4
Dairy (%)	15.6	17.3	12.9	16.6
Meat (%)	33.0	24.3	32.7	39.1
Eggs (%)	13.1	11.3	13.1	14.2
Vitamin A-rich fruits/veg (%)	68.9	47.7	73.0	80.2
Other fruits/veg (%)	27.6	18.1	28.0	33.6
Minimum Dietary Diversity[3] (%)	28.0	21.8	27.3	32.6
Use own feeding dish[4] (%)	84.5	84.4	85.2	84.0
Thick consistency[4,5] (%)	74.5	60.5	76.9	82.2
Portion size, mL[4,6]	99 (60, 140)	89 (46, 104)	97 (57, 140)	108 (88, 155)

[1]Measured via the Household Food Insecurity Access Scale [24]

[2]Values are means ± standard deviations

[3]Based on 24-hour recall period, using World Health Organization methodology [2, 3]

[4]Based on usual practice reported by caregiver

[5]Thick consistency defined as caregiver selecting photographs depicting porridges with energy density of 0.8 kilocalorie/gram or higher [1]

[6]Values are medians (interquartile ranges)

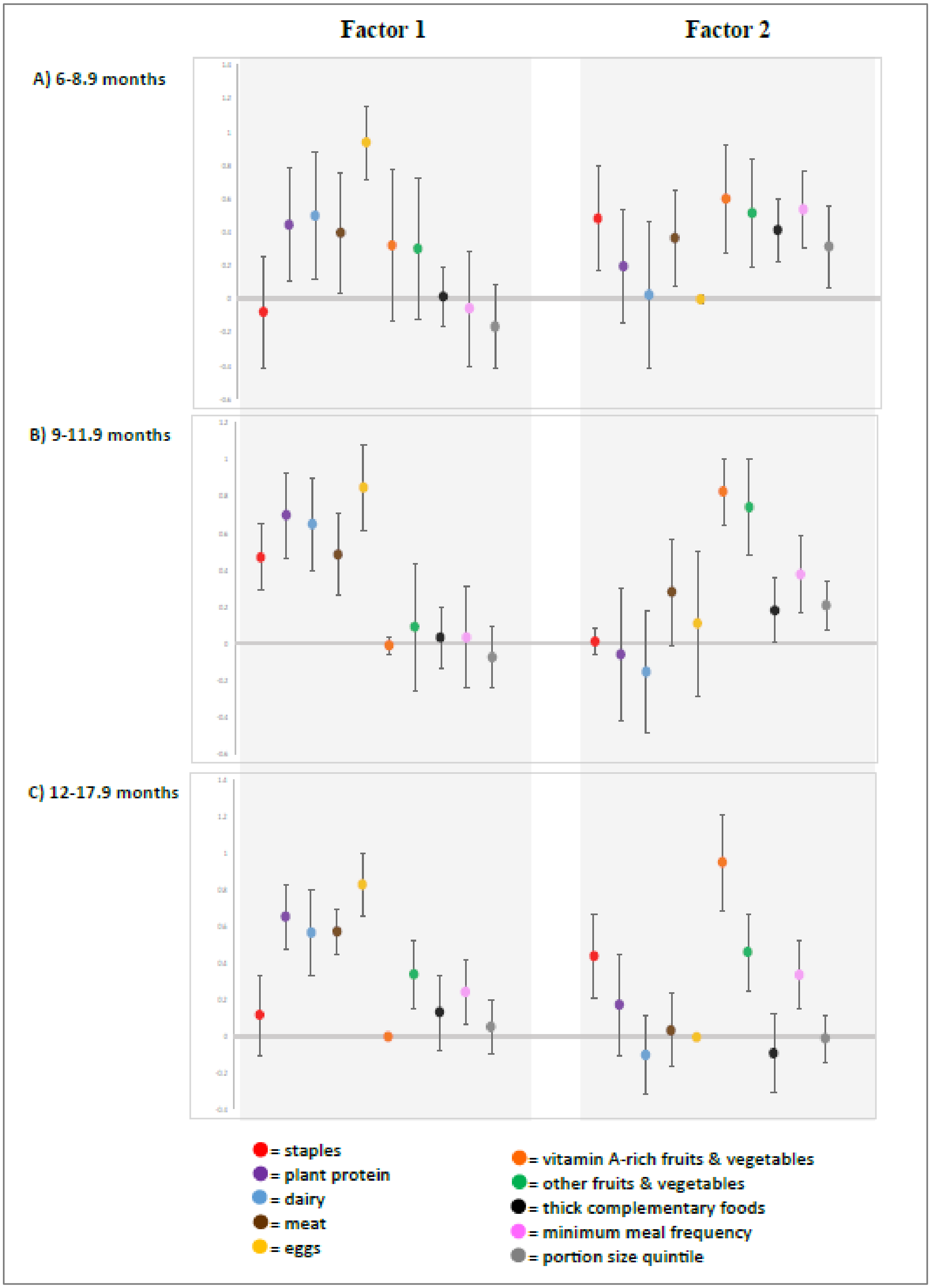

Figure 5-1. Factor loadings and 95% confidence intervals resulting from exploratory factor analysis by age group.

Table 5-2. Factor loadings and fit statistics of EFA for complementary feeding indicators.

	6-8.9 MONTHS n = 371		**9-11.9 MONTHS** n = 404		**12-17.9 MONTHS** n = 550	
	FACTOR 1	**FACTOR 2**	**FACTOR 1**	**FACTOR 2**	**FACTOR 1**	**FACTOR 2**
FACTOR INDICATORS						
Staples	-0.081	0.479*	0.468*	0.008	0.114	0.436*
Plant protein	0.443*	0.193	0.697*	-0.061	0.650*	0.17
Dairy	0.498*	0.023	0.649*	-0.156	0.564*	-0.103
Meat	0.393*	0.363*	0.482*	0.279	0.570*	0.029
Eggs	0.936*	-0.005	0.848*	0.106	0.825*	-0.008
Vitamin A-rich fruits & veg	0.32	0.600*	-0.013	0.827*	-0.004	0.946*
Other fruits & veg	0.299	0.514*	0.089	0.740*	0.335*	0.456*
Thick complementary foods	0.012	0.411*	0.031	0.178*	0.129	-0.096
Minimum meal frequency	-0.06	0.533*	0.03	0.374*	0.238*	0.333*
Portion size quintile	-0.171	0.312*	-0.077	0.206*	0.047	-0.014
Factor Correlation	**0.441***		**0.386***		**0.318***	
chi-square p-value	0.08		0.09		0.04	
RMSEA (90% CI)	0.034 (0.000, 0.057)		0.031 (0.000, 0.054)		0.031 (0.008, 0.050)	
CFI	0.968		0.965		0.955	
TLI	0.945		0.940		0.921	
SRMR	0.064		0.067		0.062	

* Significant at $p < 0.05$

Abbreviations: RMSEA, root mean square error of approximation; CI, confidence interval; CFI, Comparative Fit Index; TLI, Tucker-Lewis Index; SRMR, standardized root mean square residual

Table 5-3. Relationships between potential predictors of infant and young child feeding and latent complementary feeding factors.

	6-8.9 months n = 371				9-11.9 months n = 404				12-17.9 months n = 550			
	FACTOR 1		FACTOR 2		FACTOR 1		FACTOR 2		FACTOR 1		FACTOR 2	
Age, months	0.05		0.68	***	0.10		0.14		0.12	*	0.04	
Female sex	-0.03		0.15		-0.10		0.08		0.09		0.10	
Traditional Authority												
Mduwa = ref.												
Zulu	1.05	***	0.36		0.83	*	0.24		1.80	***	-0.15	
Mkanda	0.34		0.17		0.46	*	-0.22		1.03	***	-0.18	
Moderate or Severe Food Insecurity[1]	-0.47	*	-0.04		-0.44	*	-0.81	***	-0.16		-0.16	
Caregiver is household head	0.33		-0.98	**	-0.14		0.06		0.18		-0.30	
Wealth Tercile												
Lowest tercile = ref.	Ref.											
Middle tercile	0.06		0.09		0.38		-0.06		0.35	*	0.25	
Highest tercile	0.28		0.13		0.55	*	-0.08		0.44	*	0.12	
Caregiver completed primary school	-0.16		0.25		0.17		0.20		0.04		0.88	***
Child receives own feeding dish	0.71	**	0.01		0.25		-0.15		0.32		0.30	
Child had diarrhea in the previous day	0.04		0.16		-0.17		0.12		0.13		0.01	

* $p < 0.05$, ** $p \le 0.01$, *** $p \le 0.001$

[1]Measured via the Household Food Insecurity Access Scale [24]

Chapter 6 - A Nutrition-Sensitive, Orange-Fleshed Sweet Potato Project in Southern Ethiopia Improves Complementary Feeding Practices: An Examination of Potential Impact Pathways

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Abstract.

Introduction. Quality Diets for Better Health is a nutrition-sensitive project that aims to improve the diets of infants and young children through community-based nutrition education and promotion of homestead production of orange-fleshed sweet potatoes (OFSP) that are bio-fortified for vitamin A-richness. The project also tests the added benefit of a Healthy Baby Toolkit (HBT), which promotes optimal infant and young child feeding.

Objective. The present study is a cluster-randomized controlled trial in which we use mediation analysis to assess potential impact pathways through which the Quality Diets for Better Health project may affect complementary feeding outcomes.

Methods. Six *kebeles* (villages) were randomly selected to receive OFSP promotion and nutrition education; seven *kebeles* were randomly selected to receive the HBT in addition to nutrition education and OFSP promotion, and seven *kebeles* were randomly selected to act as controls. A baseline survey of 605 households with infants birth to six months was conducted in December 2017 and January 2018. A follow-up survey was conducted with the same households approximately six months later, after implementation of the project and when all infants were at least six months of age. At both baseline and follow-up, we assessed food security and knowledge of complementary feeding practices. At follow-up, we assessed infant and young child feeding practices, and infant dietary intake using multiple-pass 24-hour dietary recall. We constructed a summary complementary feeding index, comprised of feeding frequency, dietary diversity, complementary food consistency, and portion size. We used mediation analysis to assess whether knowledge of complementary feeding recommendations and/or food security are impact pathways by which the program affects complementary feeding practices, energy intake, and vitamin A intake, while controlling for covariates.

Results. A total of 605 households participated in the baseline survey, including 269 (44.5%) in the control group, 154 (25.5%) in the partial intervention, and 182 (30.1%) in the full intervention. Of those, 548 households (90.6%) completed the follow-up survey. At baseline, there were no differences in food security ($p=0.90$), and households in the control group had slightly higher knowledge scores ($p<0.01$). In adjusted models, food security scores at follow-up were higher in the partial ($\beta=0.99$, 97.5% CI 0.55, 1.43) and full ($\beta=0.97$, 97.5% CI 0.60, 1.35) intervention than in control. Knowledge scores were also higher in both partial ($\beta=0.89$, 97.5% CI 0.49, 1.28) and full ($\beta=1.10$, 97.5% CI 0.76, 1.45) intervention than in control. In both intervention groups, nutrition knowledge mediated modest impacts on energy intake and the summary complementary feeding index, particularly on minimum feeding frequency, portion size, and feeding thick complementary foods. Food security mediated modest impacts on dietary diversity. Additionally, the full intervention exerted a strong effect on the summary complementary feeding index, dietary diversity, and portion size that was not explained by either mediator, and was not seen in the partial intervention group.

Conclusion. In conclusion, the Quality Diets for Better Health project improved food security and knowledge of complementary feeding, which led to modest improvements in complementary feeding outcomes. The HBT exerted a strong, direct effect on dietary diversity and portion size, and may act as an important cue to action for improved complementary feeding practices.

6.1 Introduction

Childhood undernutrition remains the leading cause of disability-adjusted life years in sub-Saharan Africa [1]. Appropriate complementary feeding from 6 to 23.9 months is an important facet of ensuring appropriate growth and development in the critical first two years of life [2], but adherence to complementary feeding recommendations remains poor in low- and middle-income countries [3, 4].

Researchers from Emory University and the Georgia Institute of Technology developed a set of tools – referred to here as the Healthy Baby Toolkit (HBT) – to act as simple educational resource and cue to promote optimal maternal nutrition and complementary feeding practices [5, 6]. The tools were developed in accordance with the Health Belief Model [5], which seeks to understand one's readiness for behavior change with respect to his or her perceptions about risks, benefits, and self-efficacy [7]. The Health Belief Model also recognizes the role of "cues to action" as an impetus for adopting a certain behavior [7]. The HBT consists of three items: (1) a feeding bowl with graduated demarcations and symbols to promote age-appropriate feeding frequency and portion size; (2) a slotted spoon to cue caregivers to prepare thicker consistency foods (such that complementary food will not drip through the holes in the spoon); and (3) a counseling card that uses context-specific images to reinforce messages of the bowl and spoon, and to promote dietary diversity and hygienic food preparation and feeding. The HBT has been qualitatively evaluated in Bihar, India [6]; Western Kenya [5]; and Mchinji, Malawi [8], receiving generally positive responses in all. In 2015 to 2016, Concern Worldwide conducted operations research to quantitatively evaluate the impact of the HBT on complementary feeding; improvements in several complementary feeding practices were achieved among households receiving the HBT [9]. Caregivers continued to use the HBT, but cited food insecurity as the greatest barrier they faced to properly using the tools [9].

Nutrition education interventions can improve complementary feeding practices [10], but their impact is likely enhanced when underlying causes, such as food insecurity, are also addressed [11, 12]. Nutrition-sensitive programs, often combined with or used as a platform for nutrition-specific interventions, address underlying causes of undernutrition and can have a wider reach than nutrition-specific interventions alone [13]. Nutrition-sensitive agriculture programs often target food insecure communities that primarily rely on subsistence agriculture for livelihoods. The benefits of orange-fleshed sweet potato (OFSP) projects, in particular, are manifold. Campaigns to promote OFSP that are bio-fortified for vitamin A-richness have a demonstrated history of improving vitamin A status and/or intake in sub-Saharan Africa [14-18]. Further, sweet potato roots can yield more energy per hectare of land than other staples, and leaves and vines may be used for human and animal consumption, making sweet potatoes an important food security crop [19, 20].

Infant and young child nutrition in the Southern Nations, Nationalities, and Peoples' Region (SNNPR), Ethiopia is wanting. In 2016, only 41.4% and 13.0% of children 6 to 23.9 months in the region met minimum meal frequency and minimum dietary diversity recommendations, respectively, and fewer than half (48.2%) had consumed a vitamin A-rich food in the previous day [21]. Overall estimated energy and protein intakes of children are lower in SNNPR than any other region of the country [22].

In the present study, we used a three-arm cluster randomized controlled design to test potential impact pathways of an integrated OFSP and nutrition education project on complementary feeding outcomes in southern Ethiopia, including the potential additive effects of the HBT.

6.2 Methods

6.2.1 Description of intervention

Quality Diets for Better Health (QDBH) is a 54-month, nutrition-sensitive agriculture project that aims to improve the diets of young children through the homestead production of OFSP and nutrition education. Project implemented is led by the International Potato Center (CIP), in partnership with People in Need (PIN), Emory University, and the Southern Agriculture Research Institute and with support from local government offices.

The project reaches subsistence farmers and their families primarily through the formation of "Healthy Living Clubs" (HLCs); an HLC is a group of 30 households that meets approximately monthly for nutrition and/or agriculture training, and is usually led by a volunteer member of the government's Health Development Army who underwent additional training for the project. Households in HLCs receive OFSP vines; the project also trains and supports Agriculture Development Agents in the project communities to provide appropriate support for OFSP farming. A subset of households also receive the HBT. Prior to project implementation, formative research was conducted to assess the acceptability of the HBT and inform the design of the nutrition education component of HLCs. Results of the formative research suggested that the HBT is generally acceptable, though suggestions for improvement were incorporated into the design of the HBT and overall nutrition education. Namely, caregivers did not want a transparent feeding bowl, as allowing a child's food to be seen is taboo and some caregivers believe it predisposes a child to illness; therefore, the tools were produced opaque, and orange was chosen for the bowl and spoon to tie into OFSP promotion materials [23]. In incorporating results of the formative research into the nutrition curriculum for HLCs, a behavior change framework described by Michie *et al*. was applied to complementary feeding behaviors; Michie's behavior change framework considers behavioral determinants as reflecting capability, opportunity, and/or motivation [24].

The project is designed for implementation in 13 *kebeles* (the smallest administrative unit in Ethiopia) in the first year, with eventual scale up to 41 *kebeles* over the course of the project. Of the 41 *kebeles* participating in the project, 26 were identified as eligible for project activities in the first year based on having at least moderate potential for OFSP growth and the absence of other nutrition-specific or nutrition-sensitive programs (aside from standard activities implemented by the government's Health Extension Program). From the 26 *kebeles* eligible for year 1 activities, six were randomly selected to receive the standard QDBH project activities including OFSP promotion and nutrition education ("partial intervention"), seven were randomly selected to receive the HBT in addition to standard activities included in partial intervention ("full intervention"), and seven were randomly selected to act as controls. The QDBH project will be implemented in the seven control *kebeles* in the third year of project scale up, and will be implemented in the *kebeles* that were not randomly selected for evaluation activities in either the second or third year of the project.

In September 2017, a household listing of all households in each of the seven full intervention, six partial intervention, and seven control *kebeles* was undertaken by CIP and PIN. These household listings were used to identify households eligible for participation in HLCs. Households are eligible to participate in HLCs and receive OFSP vines if they have a pregnant woman or child under two years, and have at least 30 square-meters of land to dedicate to OFSP farming. Households with women in the last trimester of their pregnancy or with infants under 6 months of age were preferentially enrolled in HLCs. Orange-fleshed sweet potato vines were distributed in November 2017, and HLCs began in February 2018.

6.2.2 Study Design and Eligibility

A one-year longitudinal study was designed to evaluate the impact of the project, with vitamin A and energy intake being primary outcomes. Households from intervention *kebeles* were eligible for enrollment if they participated in an HLC, had an infant under 6 months, and if the caregiver and head of household (if available) provided informed consent. In control *kebeles*, eligible households were identified based on the household listing and by working closely with community health workers and leaders to identify eligible households, defined as any household with an infant under 6 months and whose caregiver and head of household (if available) provided informed consent. Infants with serious health problems were excluded. All eligible households were enrolled in December 2017 to January 2018 and completed a baseline survey at that time. Follow-up midline and endline surveys were conducted in August 2018 and February 2019, respectively. The research presented here uses data through the midline survey (henceforth referred to as follow-up) to assess project impact on both primary and secondary outcomes. At the time of the first follow-up survey, the HLC curriculum had been fully implemented and households in intervention communities were "graduating" from the program around the time of the survey.

6.2.3 Data collection

Data on household sociodemographic characteristics, including caregiver and head of household characteristics, household ownership of durable goods, and housing characteristics; household food insecurity; access to water and sanitation facilities; caregiver nutrition knowledge; infant feeding practices; basic infant health information; and infant anthropometry were collected at baseline. All data were collected in one household visit. The follow-up survey consisted of two data collection time points, and included multiple-pass 24-hour dietary recall of infant diets as described by Gibson and Ferguson [25]. Initially, groups of caregivers were asked to meet at common locations (such as a school, church, or government health post) two or three days prior to their scheduled household visit. At that visit, caregivers completed a short questionnaire assessing their nutrition knowledge, household food security, project participation, and duration of exclusive breastfeeding; maternal (if applicable) and child anthropometry were also assessed. Caregivers were also introduced to the multiple-pass 24-hour dietary recall methodology, described Gibson and Ferguson [25], and were given an appointment date and time for either two or three days later. Caregivers were provided with a small plastic bowl for feeding the child separately in order to enable portion size estimation, and a food picture chart and pencil for marking foods given on the assigned observation day.

At the household visit, research assistants administered an additional questionnaire collecting data on infant and young child feeding practices, receipt of educational training tools, and the multiple-pass 24-hour dietary recall of the infant diet. The 24-hour dietary recall consisted of four passes: (1) listing all foods and beverages consumed other than breastmilk and water; (2) collecting a detailed description of each food and beverage based on pre-specified probing questions for each food or beverage; (3) estimating amounts consumed using food photographs, playdough, directly weighing foods, and/or using uncooked rice to demonstrate amounts consumed; and (4) review of information from the previous three passes.

6.2.4 Variable specification

A household wealth index was developed using principal component analysis to assign indicator weights to a series of household-level indicators [26, 27]. Indicators included in the index are ownership of household goods, housing characteristics, cooking location, access to drinking water and sanitation facilities, and access to utilities, all assessed at baseline. Any binary indicator with less than 5% or more than 95% affirmative responses were considered to have insufficient variability and were not included in the wealth index; similarly, any categorical variable with a group having less than 5% responses was collapsed with another similar category.

A nutrition knowledge score was developed based on caregiver responses to knowledge questions addressing the following domains: behaviors that promote child growth (2 points); vitamin A awareness, benefits, and food sources (3 points); colostrum (1 point); timely introduction of diverse complementary foods (2 points); timely introduction of thick complementary foods (2 points); feeding frequency (2 points); and portion size (2 points). Questions included in the index and their scoring are shown in Supplemental Table 6-1. Missing responses to nutrition knowledge questions were imputed with the *kebele*-average for that question so as to retain sample size and limit biases. Nutrition knowledge questions were asked at both baseline and follow-up; however, the vitamin A domain was excluded from the baseline knowledge score for the purpose of these analyses. The reason for the exclusion of the vitamin A domain from the baseline knowledge score is that OFSP vine distribution had occurred just prior to the baseline survey. While no formal nutrition education had taken place prior to the baseline survey, part of the campaign to distribute OFSP vines in intervention communities included educating households about the health benefits of OFSP compared to other starchy staples as a means of encouraging farmers to dedicate land to OFSP. Thus, their vitamin A knowledge could have been impacted.

The Food Insecurity Experience Scale (FIES) was used to assess food insecurity with a one-year recall period at baseline [28]. Because follow-up occurred within 6 months of baseline, the FIES at follow up used a 4 week recall period. The FIES has previously been found to be appropriate for use in several sub-Saharan African countries, including Ethiopia [29]. A higher FIES score is associated with greater food insecurity. To enable interpretability, the FIES raw score was reverse-coded such that higher reverse-coded FIES scores (rFIES) are associated with greater food security.

Energy and vitamin A intake were estimated based on multiple-pass 24-hour recalls. A food composition database was compiled based on existing food composition tables from Ethiopia, Uganda [30], and/or the United States Department of Agriculture [31] where necessary. Based on formative work prior to the follow-up survey, several commonly consumed mixed dishes were pre-identified as being dishes with standard recipes. For these dishes, we invited two to four women from two to four communities of interest to prepare the dish such that all ingredients could be weighed and the final volume and weight of the dish could be measured; women were provided with all necessary ingredients, cooking materials, and cooking fuel. For each recipe, average ingredient proportions were taken in order to identify nutrient content of the standard mixed dishes. For any mixed dish that was not considered standard, a unique household recipe was collected by asking the person who prepared the dish to list and describe all ingredients, and then estimate amounts of each ingredient using previously described techniques.

World Health Organization (WHO) protocols were followed for indicators of feeding frequency and dietary diversity in the previous day [32, 33]. We assessed normal complementary food consistency by showing caregivers five photographs of porridge of different energy densities and asking her to select the photograph most closely matching the food given to her child. The photographed porridges were prepared using boiling water, maize flour, and vegetable oil to match common ingredients used to prepare complementary foods that were identified based on formative research. The energy densities of the five photographed porridges were 0.08 kilocalorie per gram (kcal/g), 0.36 kcal/g, 0.66 kcal/g, 0.94 kcal/g, and 1.25 kcal/g. Portion sizes were estimated by asking caregivers to use uncooked rice to demonstrate portion sizes; the uncooked rice was then transferred to a measurement cylinder and recorded to the nearest milliliter (mL). Caregivers were asked to use their child's normal feeding dish to demonstrate portion sizes offered, and amount left uneaten, if applicable, such that quantity consumed could be estimated. If the child normally ate from a shared plate, then the caregiver used the uncooked rice to estimate the amount consumed. The estimated portion sizes were ranked and classified by age-specific quintile for infants 6 to 8.9 months, 9 to 11.9 months, and 12 to 13.9 months. We tabulated a Complementary Feeding Index (CFI), which assigns points for age-specific feeding frequency, dietary diversity, complementary food consistency, and portion size; a total of 8 points are possible based on the point allocation shown in Table 6-1. The index is adapted from an index developed by Ruel and Menon [34].

6.2.5 Statistical Approach

Continuous variables were assessed for normality and the presence of outliers. For energy intake from complementary foods, we assessed the distribution by age group (6 to 8.9 months, 9 to 11.9 months, and 12 to 13.9 months). Energy intakes that were more than 3 age group-specific standard deviations above the age group-specific means were excluded from analysis. Proportions for categorical variables, means ± standard deviations for normally distributed continuous variables, and medians and interquartile ranges (IQR) for non-normally distributed continuous variables are reported for relevant characteristics at each time point. We compared key variables of interest across intervention groups with chi-square tests for categorical variables and unadjusted linear regression for continuous variables. All descriptive and baseline comparisons were conducted with SAS-callable SUDAAN (SAS 9.4, SAS Institute Inc., Cary, NC, USA; SUDAAN 11, RTI International, Research Triangle Park, NC, USA) to account for clustering of *kebeles*.

Prior to testing mediation models, we first assessed whether intervention group modified the relationships between the hypothesized mediators (nutrition knowledge and food security) and the outcomes of interest using linear (for continuous outcomes) or logistic (for categorical outcomes) regressions with two-way interaction terms. A p-value of less than 0.05 for interaction terms was considered evidence of interaction. When there was no evidence of interaction, we used the *MODEL INDIRECT* command in Mplus version 7.4 (Muthen and Muthen, Los Angeles, CA, USA) to estimate total effects, direct effects of the project on complementary feeding, and indirect effects through two mediators as recommended by Hayes and Preacher for mediation analysis with a multi-categorical exposure variable (Figure 6-1) [35]. This approach creates two indicator variables for three exposure groups, in this case, with the control group being the reference group. The use of two indicator variables for three exposure groups doubles the number of parameters estimated, and therefore we present 97.5% confidence intervals, which are Bonferroni-adjusted. Confidence intervals were computed based on bootstrapped standard errors with 10,000 repetitions. Hayes and Preacher advocate for this approach because it does not make assumptions about the distribution of indirect effects [35]. Separate models were run with the following outcomes: energy intake, vitamin A intake, CFI, and each individual component of the

CFI. Covariates included in the model were identified *a priori* and included: household wealth index, child sex, child age in months, household size, whether anyone in the household earned off-farm income, *woreda*, caregiver education, baseline women's dietary diversity [36], baseline food security, and baseline nutrition knowledge excluding the vitamin A domain. Where the outcome variable is continuous, the estimated parameters are linear regressions coefficients; where the outcome variable is categorical, the estimated parameters are probit regressions coefficients, with the value representing the expected change in z-score of the outcome variable with a one-unit change in the predictor variable. We were unable to account for clustering due to the small number of *kebeles;* however, we included *woreda* as a covariate in the model (the 20 *kebeles* lie within 3 *woredas*).

For simplicity, we use the term *direct effect* throughout to represent the combinations of effects not explained by the mediators as measured that were included in the model. We acknowledge that this term may be misleading, given that we have not exhausted every theoretically possible mediator.

A target sample size of 600 was sought based on the following parameters: type I error rate of 0.05, 80% power, anticipated difference in energy intakes of 100-150 kcal, 10-15% coefficient of variation, intra-cluster correlation coefficient of 0.05, and 30% loss to follow-up.

6.2.6 Ethical approval

Ethical approval was obtained by Emory University's Institutional Review Board, and from the Southern Nations, Nationalities, and Peoples' Regional Bureau of Health Ethical Review Committee. The trial is registered with ClinicalTrials.gov, ID NCT03423472.

6.3 Results

A total of 605 households were enrolled at baseline, with 182 (30.1%) in the full intervention group, 154 (25.4%) in partial intervention group, and 269 (44.5%) in the control group. Their baseline characteristics are shown in Table 6-2. A larger proportion of households in the control group were from Dila Zuria and fewer from Aleta Chuko, while the inverse is true of households in the partial intervention group. Households in the partial intervention group were more likely to have an off-farm source of income ($p<0.001$). Caregivers in the intervention groups had higher dietary diversity at baseline ($p<0.01$), and infants in the control group were less likely to have consumed any food or liquids other than breastmilk in the previous 7 days ($p=0.02$). There was no difference in rFIES at baseline ($p=0.90$), and nutrition knowledge scores excluding the vitamin A domain were higher in the control group (7.4 ± 1.4) than in the partial (7.0 ± 1.8) or full intervention (7.0 ± 1.7; $p<0.01$).

Of the 605 households enrolled at baseline, 548 (90.6%) completed the follow-up visit. A comparison of baseline characteristics of the sample lost to follow-up and those not lost to follow-up reveals no significant differences in key baseline characteristics between the groups (Supplemental Table 6-2). General characteristics and key variables at follow-up are shown in Table 6-3. Child age at follow-up ranged from 6 to 13 months, and averaged 10.0 ± 1.7 months. Children in the control group were slightly younger (9.6 ± 1.6 months) than in the intervention groups (partial intervention, 10.4 ± 1.5 months; full intervention, 10.2 ± 1.9 months; $p<0.001$). Only 46.2% and 57.7% of households in partial and full intervention, respectively, reported participating in a HLC. However, 62.2% of partial and 69.2% of full intervention households reported receiving OFSP vines, and 72.9% of full intervention households reported receiving the HBT materials. Overall, the sample was less food secure at follow-up, which occurred during a food insecure season, but households in the control group were the least food secure ($p<0.0001$). Similarly, overall nutrition knowledge scores were lower at follow-up for all arms, but were lowest among households in the control group ($p<0.0001$).

Only one child was not breastfed at follow-up, and bottle use was rare (5.9%), with no differences between groups (p=0.60 and 0.62, respectively). A higher proportion of children in the intervention groups received any solid, semi-solid, or soft complementary foods in the previous day compared with controls (92.3%, 98.6%, and 99.4% for control, partial, and full intervention, respectively, $p<0.01$). A majority met minimum meal frequency, defined as 2 meals per day for infants 6 to 8.9 months (93.3%) and 3 meals per day for children 9 to 11.9 months (78.0%) and 12 to 13.9 months (85.3%), and there were no differences by intervention group (p=0.92, 0.18, and 0.21, respectively). Also in unadjusted models at follow-up, children in the control group had lower dietary diversity (2.1 ± 1.2 food groups) than children in the partial (2.6 ± 1.2 food groups) or full intervention (2.8 ± 1.3 food groups; $p<0.0001$). The proportion of children in the control group receiving thick complementary foods (75.1%) was less than the full intervention (89.0%; $p<0.01$). In unadjusted models, portion size was not significantly different between intervention groups, with an overall median of 55 mL (IQR 39, 79; p=0.07). The CFI was normally distributed, and was lowest in the control group (5.7 ± 1.7) and highest in the full intervention (6.7 ± 1.3; $p<0.0001$).

Eight children had energy intakes greater than 3 standard deviations above the age-specific mean and were excluded from analysis of energy intake. Once these observations were excluded, energy intake was distributed normally, and was lowest in the control group (360 ± 271 kcal) and highest in the full intervention (438 ± 281 kcal; p=0.02) in unadjusted analysis. Vitamin A intake did not differ between groups (p=0.96). Its distribution was right-skewed and zero-inflated, with 27.3% of children having no vitamin A intake in the previous day, which prevented transformation of vitamin A intake to achieve a normal distribution. Therefore, we categorized children as having no vitamin A intake (27.3%), less than 100 mcg retinol activity equivalents (RAE; 41.6%), less than 200 mcg RAE (16.4%), or greater than or equal to 200 mcg RAE (16.2%). These cutoffs correspond to meeting 0%, 25% and 50% of the WHO-recommended vitamin A intakes for children 7 months to 3 years [37].

The intervention did not modify any relationship between nutrition knowledge or food security and the outcomes of interest. Results of adjusted mediation models are shown in Table 6-4. In adjusted models, rFIES scores were higher in both the partial (0.99, 97.5% CI 0.55, 1.43) and full intervention (0.97, 97.5% CI 060, 1.35) compared to control. Nutrition knowledge scores were also higher in both partial (0.89, 97.5% CI 0.49, 1.28) and full (1.10, 97.5% CI 0.76, 1.45) intervention groups compared to control.

Nutrition knowledge, but not food security, mediated the effect of both partial (β=0.13, 97.5% CI=0.06, 0.25) and full intervention (β=0.16, 97.5% CI=0.08, 0.28) on CFI. In addition, the full intervention had a direct effect on CFI (β=0.54, 97.5% CI=0.21, 0.86) that was not explained by either mediator. Nutrition knowledge also mediated improved meal frequency in the partial (β=0.11, 97.5% CI 0.03, 0.20) and full interventions (β=0.13, 97.5% CI 0.04, 0.24). Food security mediated an indirect effect of partial (β=0.10, 97.5% CI 0.04, 0.19) and full intervention (β=0.10, 97.5% CI 0.04, 0.18) on reported child dietary diversity score; there was also a significant direct effect of the full intervention on child dietary diversity score (β=0.37, 97.5% CI 0.10, 0.63) that was not explained by either mediator. Nutrition knowledge mediated indirect effects of partial (β=1.8, 97.5% CI 0.5, 3.9) and full intervention (β=2.3, 97.5% CI 0.6, 4.4) on reported portion size quintile; there was also a direct effect of the full intervention on portion size quintile (β=0.30, 97.5% CI 0.10, 0.63) that was not explained by either mediation. Nutrition knowledge also mediated indirect effects on caregiver reported complementary food thickness in both partial (β=0.09, 97.5% CI 0.03, 0.17) and full intervention (β=0.11, 97.5% CI 0.04, 0.19).

There were significant indirect effects of partial (β=10.9, 97.5% CI 1.4, 25.0) and full intervention (β=13.0, 97.5% CI 1.3, 27.6) through nutrition knowledge on energy intake. There was a significant but negative effect of partial intervention on energy intake (β=-61.2, 97.5% CI -113.5, -9.5) that was not explained by either mediator; there was no significant direct effect of the full intervention on energy intake (β=16.4, 97.5% CI -34.9, 69.2). There were no significant effects on vitamin A intake.

6.4 Discussion

The QDBH intervention led to improved household food security and nutrition knowledge, and each mediated modest improvements in complementary feeding outcomes. Nutrition knowledge mediated the effects of the QDBH project on the summary CFI as well as some individual complementary feeding practices and overall energy intake from complementary foods, while food security mediated improved dietary diversity. Similar nutrition-sensitive OFSP-promotion projects have achieved improvement in nutrition knowledge [14, 15, 38]. De Brauw *et al*. examined the potential mediating effect of nutrition knowledge on OFSP adoption and vitamin A intakes of young children in Uganda and Mozambique, and concluded that nutrition knowledge had either no or only a small role as a mediator [39]. However, in these studies, nutrition knowledge was more narrowly defined only as knowing facts about vitamin A and knowledge of OFSP as a source of vitamin A [39]. Little published research has explored the impacts of OFSP-promotion on food security.

The full intervention exerted strong effects on dietary diversity, portion size, and the summary CFI that were not mediated by either nutrition knowledge or food security, and were not seen in the partial intervention. Receipt of the HBT was designed to be the sole difference between partial and full intervention groups. Some project indicators – including participation in HLCs, and receipt of OFSP vines and printed materials – were higher in the full intervention than in partial. However, the magnitude of the effects of full and partial intervention on food security and nutrition knowledge were similar, suggesting the differences in project participation are unlikely to explain the direct effect of the full intervention and absence of a direct effect in partial intervention. In both intervention groups, the proportion who reported participation in a HLC was lower than anticipated, given that membership in a HLC was an eligibility criterion for enrollment at baseline. It is possible that households were initially enrolled to participate in an HLC, but discontinued their attendance. However, greater numbers of households reported receiving printed materials and/or feeding toolkits than participating in HLCs, but these materials were distributed at HLCs. Multiple languages are spoken in the project area, and a possible explanation is that, despite the involvement of local project staff in survey translation, the terms used for HLC were unfamiliar to participants or improperly translated.

The Health Belief Model recognizes the importance of cues to action for achieving behavior change [7]. In this regard, the presence and use of the HBT may explain the strong, direct effects on complementary feeding practices that were not explained by either mediator and were only observed in the full intervention. That the size of dishware acts as a cue to influence portion sizes is recognized in obesity prevention and weight loss literature [40, 41]. The results observed here suggest a similar mechanism may operate to promote larger portion sizes in a setting with a high burden of undernutrition. An explanation for the HBT's impact on dietary diversity is less clear, as households in the partial intervention received very similar printed education materials with respect to dietary diversity. However, the feeding bowl and spoon were orange, which matched other promotional materials utilized by the project, intentionally designed to generate awareness around OFSP and vitamin A-rich foods.

A notable finding is the increase in child dietary diversity score of nearly 0.5 food groups in the full intervention group, resulting from both direct and indirect effects. The Alive and Thrive project was a nutrition specific social and behavior change program that aimed to improve infant and young child feeding practices in SNNPR. Using a non-controlled repeat cross-sectional evaluation design, they noted dietary diversity scores among children 6 to 23.9 months increased from 1.7 in 2010 to 2.1 in 2014. Of this increase, they attributed 0.3 food groups to project activities [42]. However, the proportions of children meeting minimum dietary diversity in 2010 and 2014 were similar to national trends reported in the Demographic and Health Surveys for Ethiopia in 2011 and 2016 [21, 43]. The sample analyzed here ranges only from 6 to 13 months, and the follow-up survey was done during a time of low food security, which could affect the magnitude of the impact observed and make cross-project comparisons difficult.

It is somewhat contradictory to find a significant total effect of the full intervention on portion size, but not on energy intake from complementary foods. In Chapter 4, we have demonstrated that portion size and energy intake from complementary foods are correlated. However, estimated portion size was based on usual intake, where estimated energy intake was based on recall of the previous day only. Having repeat multiple-pass 24-hour dietary recall would be more reflective of a child's usual intake; single day recall tends to be less precise. Furthermore, total energy intake reflects not only portion size, but also the energy density of the food consumed and the number of feeding episodes per day.

Strengths and Limitations.

The findings presented here may have limited external validity. The 20 *kebeles* involved in this impact evaluation were considered eligible based on having the best potential for OFSP production and an absence of nutrition programs beyond the government's standard Health Extension Program. Therefore, the conditions in these *kebeles* are not generalizable, and represent the best potential for impact.

Furthermore, there may be unknown and unmeasured confounding. *Kebeles* receiving each level of the exposure were randomly assigned, which in theory reduces risk of confounding by unmeasured variables. However, in mediation analysis, a main concern is potential unmeasured confounding of the relationship between the mediator(s) and the outcomes, a concern which is not ameliorated by randomization of the exposure variable. While we have included a number of potential confounders specified *a priori*, there is always potential for confounding by unknown variables. Furthermore, the number of clusters was too few to use multilevel or clustering analytical methodologies in the mediation analysis, thus the confidence intervals presented here could be too narrow and may increase risk of type I error. However, we have controlled for *woredas*, in which *kebeles* are located. Caregiver dietary diversity scores at baseline had an ICC of 0.07; however, after controlling for *woreda* the ICC drops to 0.03, suggesting more covariance exists at the *woreda* level.

Lastly, this research attempts to identify mediation pathways through constructs that are challenging to measure: food security and nutrition knowledge. While FIES is a validated tool that has been deemed appropriate for use in Ethiopia and other sub-Saharan African countries [28, 29], it is nevertheless a tool designed to measure a complex condition. To assess nutrition knowledge, we used similar tools that were developed in Haiti [44] and have been used in Ethiopia [45]. However, the questions included in our knowledge score were directly addressed in the HLCs, and thus the score may fail to assess more complex facets of a caregiver's knowledge of nutrition. Measurement error around these theorized mediators could bias indirect effects towards the null and exaggerate the "direct" effects seen here. Furthermore, we recognize that the term *direct effect* is, perhaps, a misnomer in that we have not exhausted every potential mediator in these analyses. Rather, the direct effects discussed here should be thought of as effects that are not explained by food security or nutrition knowledge as measured. Though food security and nutrition knowledge are the pathways through which project impact was theorized, other potential mediators that were not measured but could influence complementary feeding practices include self-efficacy, father's involvement in child feeding, women's empowerment, changing social norms, and household income (note that we did assess household wealth at baseline and have included it as a covariate, but did not attempt to measure income at any time point or changes in wealth after the baseline survey).

Despite the limitations, there are several strengths of the work. We have collected and analyzed longitudinal data, which allows us to establish temporal relationships between exposures, mediators and outcomes. Specifically, we have shown that at baseline, the intervention groups included in this trial experienced similar food insecurity, and that intervention households did not possess greater knowledge of complementary feeding recommendations. However, we see significant differences between the intervention groups and their control counterparts after implementation of the project. Furthermore, while OFSP are a well-established, nutrition-sensitive option for addressing inadequate vitamin A intake, we assess important project impact pathways on a range complementary feeding practices and outcomes. We present a quantitative evaluation of the HBT and demonstrate that the tools act as an important cue for behavior change, consistent with the Health Belief Model by which they were designed.

Conclusion

In conclusion, the QDBH project contributed to improved food security and knowledge of complementary feeding recommendations and vitamin A, these in turn, positively impacted complementary feeding of children 6 to13 months of age. The strongest impact, however, was not explained by either food security or nutrition knowledge, and was seen only among households who received feeding tools.

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Table 6-1. Scoring of the Complementary Feeding Index.

	6-8.9 months	**9-11.9 months**	**12-13.9 months**
Dietary Diversity[1]	≤ 1 food group: +0 2-3 food groups: +1 ≥ 4 food groups: +2	≤ 1 food group: +0 2-3 food groups: +1 ≥ 4 food groups: +2	≤ 1 food group: +0 2-3 food groups: +1 ≥ 4 food groups: +2
Meal Frequency[1]	0 meals: +0 1 meal: +1 ≥ 2 meals: +2	0 meals: +0 1-2 meals: +1 ≥ 3 meals: +2	0 meals: +0 1-2 meals: +1 ≥ 3 meals: +2
Consistency[2]	Photograph 1 or 2: +0 Photograph 3, 4, or 5: +2	Photograph 1 or 2: +0 Photograph 3, 4, or 5: +2	Photograph 1 or 2: +0 Photograph 3, 4, or 5: +2
Volume[2]	Quintile 1: +0 Quintile 2: +0.5 Quintile 3: +1 Quintile 4: +1.5 Quintile 5: +2	Quintile 1: +0 Quintile 2: +0.5 Quintile 3: +1 Quintile 4: +1.5 Quintile 5: +2	Quintile 1: +0 Quintile 2: +0.5 Quintile 3: +1 Quintile 4: +1.5 Quintile 5: +2
Total Possible	**8 points**	**8 points**	**8 points**

[1]Based on 24-hour recall period

[2]Based on self-reported usual practice

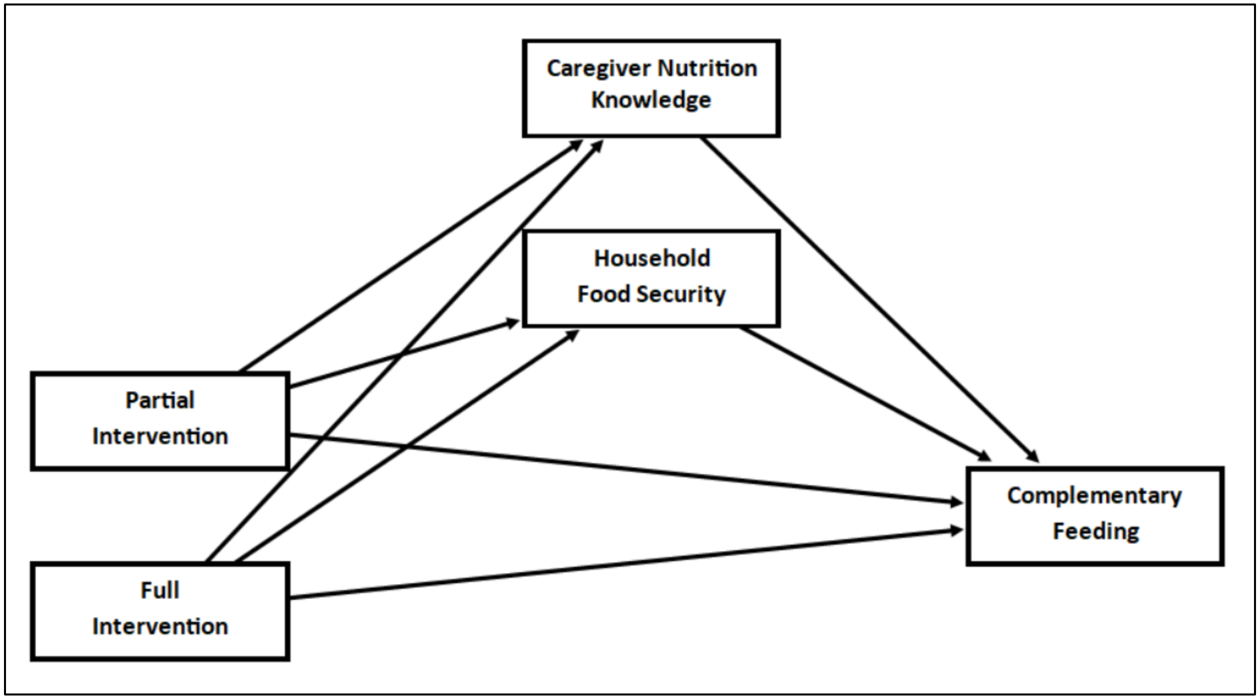

Figure 6-1. Model to test mediation of caregiver nutrition knowledge and household food security on complementary feeding outcomes.

Table 6-2. Baseline characteristics of households with children birth to 6 months in the Quality Diets for Better Health longitudinal study.

	Total N = 605	Control n = 269	Partial Intervention n = 154	Full Intervention n = 182	p-value
Household sociodemographic characteristics					
Woreda					
Aleta Chuko (%)	40.3	21.6	62.3	49.5	<0.0001
Dila Zuria (%)	40.5	54.7	23.4	34.1	
Gedeo (%)	19.2	23.8	14.3	16.5	
Caregiver age, years[1]	26.0 ± 5.2	26.0 ± 5.5	25.9 ± 5.5	26.3 ± 4.6	0.76
Caregiver dietary diversity score[2]	2.4 (1.6, 3.5)	2.3 (1.5, 3.3)	2.6 (1.7, 3.7)	2.6 (1.6, 3.8)	<0.01
Household size[1]	5.6 ± 2.1	5.5 ± 2.1	5.7 ± 2.2	5.6 ± 1.9	0.43
Any off-farm income (%)	55.5	51.7	72.1	47.3	<0.001
Caregiver education[2]					
Less than cycle 1 completed (%)	45.9	52.8	38.3	42.3	<0.01
Cycle 1 completed (%)	35.8	27.7	46.8	38.5	
Cycle 2 completed (%)	18.2	19.5	14.9	19.2	
Wealth Index[1]	0.00 ± 1.00	-0.01 ± 1.04	0.05 ± 0.93	-0.03 ± 1.01	0.69
Food insecurity experience scale (reverse coded)[1,3]	4.2 ± 2.9	4.2 ± 3.0	4.3 ± 2.8	4.1 ± 2.9	0.90
Knowledge score without vitamin A[1,4]	7.2 ± 1.6	7.4 ± 1.4	7.0 ± 1.8	7.0 ± 1.7	<0.01
Child Characteristics					
Female (%)	49.1	51.7	46.1	47.8	0.49
Age, months[1]	2.7 ± 1.6	2.5 ± 1.5	2.9 ± 1.5	2.7 ± 1.7	0.05
Breastfed in previous day (%)	99.7	99.6	100.0	99.5	0.36

Consumed any non-breastmilk foods or liquids in past 7 days (%)	22.5	17.5	29.2	24.2	0.02
Child Nutritional Status					
Length-for-age z score[1]	-0.4 ± 1.5	-0.9 ± 1.4	-0.1 ± 1.5	-0.1 ± 1.3	<0.0001
Stunted (%)	13.0	18.5	10.5	7.1	<0.01
Weight-for-age z score[1]	-0.2 ± 1.4	-0.3 ± 1.6	-0.1 ± 1.4	-0.1 ± 1.3	0.30
Underweight (%)	10.3	14.6	8.7	5.5	<0.01
Weight-for-length z score[1]	0.2 ± 1.8	0.5 ± 2.0	0.1 ± 1.5	-0.1 ± 1.5	<0.01
Wasted (%)	9.7	11.7	6.8	9.3	0.23

[1]Values are means ± standard deviations

[2]Cycle 1 is defined as grades 1 through 4, cycle 2 is defined as grades 5 through 8

[3]Food Insecurity Experience Scale raw score [28] subtracted from 8

[4]Nutrition knowledge score without vitamin A is an additive score based on the number of correct responses to questions about infant and young child feeding recommendations; see Supplemental Table 6-1

[5]Values are median (25th percentile, 75th percentile)

Table 6-3. Follow-up characteristics of households with children 6 to 13 months in the Quality Diets for Better Health longitudinal cohort.

	Total N = 548	**Control** n = 235	**Partial Intervention** n = 143	**Full Intervention** n = 170	**p value**
Followed-up (%)	90.6	87.4	92.9	93.4	0.08
Age, months[1]	10.0 ± 1.7	9.6 ± 1.6	10.4 ± 1.5	10.2 ± 1.9	<0.001
Project Participation					
In a Healthy Living Club within last year (%)	31.8	4.3	46.2	57.7	<0.0001
Attended training at a Farmer Training Center within last year (%)	16.6	12.4	23.1	26.5	<0.01
Received OFSP vines (%)	37.9	0.0	62.2	69.2	<0.0001
Received feeding bowl and/or spoon (%)	22.7	0.0	0.0	72.9	<0.0001
Received at least 1 printed material (%)	32.1	0.0	44.4	66.3	<0.0001
Food Insecurity Experience Scale, reverse coded[1,2]	3.2 ± 2.5	2.2 ± 1.9	4.1 ± 2.6	3.7 ± 2.7	<0.0001
Nutrition knowledge score[1,3]	6.8 ± 1.9	6.0 ± 1.9	7.3 ± 1.8	7.4 ± 1.7	<0.0001
Nutritional Status					
Length-for-age z score[1]	-1.4 ± 1.2	-1.5 ± 1.2	-1.1 ± 1.2	-1.5 ± 1.2	<0.01
Stunted (%)	30.3	34.2	21.8	32.0	0.03
Weight-for-age z score[1]	-0.6 ± 1.1	-0.7 ± 1.2	-0.4 ± 1.0	-0.7 ± 1.1	0.02
Underweight (%)	11.7	15.0	6.3	11.8	0.03
Weight-for-length z score[1]	0.2 ± 1.1	0.2 ± 1.1	0.2 ± 1.0	0.2 ± 1.1	0.88
Wasted (%)	1.8	2.2	0.7	2.4	0.32

Infant and Young Child Feeding Practices[4]					
Currently breastfed (%)	99.8	100.0	99.3	100.0	0.60
Used bottle (%)	5.9	6.9	5.6	4.7	0.62
Any solid, semi-solid, or soft foods (%)	96.2	92.3	98.6	99.4	<0.01
Minimum meal frequency (%)					
6 - 8.9 months	93.3	93.4	95.0	92.3	0.92
9 - 11.9 months	78.0	73.4	83.1	80.7	0.18
12 - 13.9 months	85.3	82.8	92.5	80.9	0.21
Child dietary diversity score[1]	2.5 ± 1.3	2.1 ± 1.2	2.6 ± 1.2	2.8 ± 1.3	<0.0001
Portion size, mL[5]	55 (39, 79)	51 (35, 74)	55 (40, 76)	64 (42, 85)	0.07
Thick complementary food (%)	80.5	75.1	78.2	89.0	<0.01
Complementary Feeding Index[6]	6.2 ± 1.6	5.7 ± 1.7	6.2 ± 1.4	6.7 ± 1.3	<0.0001
Nutrient Intake[7]					
Energy intake from complementary foods, kcal	386 ± 271	360 ± 271	370 ± 251	438 ± 281	0.02
Vitamin A intake from complementary foods, mcg RAE	39 (0, 131)	17 (0, 130)	59 (7, 124)	65 (2, 133)	0.96
Vitamin A intake from complementary foods					0.05
0 mcg RAE (%)	25.7	32.3	20.3	21.2	
1-99 mcg RAE (%)	41.6	36.2	49.7	42.4	
100-199 mcg RAE (%)	16.4	14.0	18.2	18.2	
≥200 mcg RAE (%)	16.2	17.5	11.9	18.2	

Abbreviations: OFSP, orange-fleshed sweet potato; kcal, kilocalorie; mcg, microgram; RAE, retinol activity equivalents; mL, milliliter

[1]Values are means ± standard deviations

[2]Food Insecurity Experience Scale raw score [28] subtracted from 8

[3]Nutrition knowledge score is an additive score based on the number of correct responses to questions about vitamin A and infant and young child feeding recommendations; see Supplemental Table 6-1

[4]Breastfeeding status; bottle use; receipt of solid, semi-solid, or soft foods; feeding frequency; and dietary diversity score are based on recall of previous day using World Health Organization methodology [32, 33], while receipt of own feeding dish; consistency; and portion size are based on usual practice as reported by caregiver

[5]Values are median (25th percentile, 75th percentile)

[6]Complementary Feeding Index is an additive score based on feeding frequency, dietary diversity, complementary food thickness, and portion size; see Table 6-1

[7]Values are estimated from multiple-pass 24-hour dietary recall

Table 6-4. Total effects, indirect effects through food security and nutrition knowledge, and direct effects of the Quality Diets for Better Health project on complementary feeding outcomes.

	Partial Intervention		**Full Intervention**	
	β	**97.5% CI**	**β**	**97.5% CI**
Food security[1,2]	0.99	0.55, 1.43	0.97	0.60, 1.35
Nutrition knowledge[1,3]	0.89	0.49, 1.28	1.10	0.76, 1.45
Complementary Feeding Index[1,4]				
Total Effect	0.08	-0.25, 0.41	0.73	0.41, 1.02
Indirect Effects				
Food security	0.03	-0.03, 0.11	0.03	-0.03, 0.10
Nutrition knowledge	0.13	0.06, 0.25	0.16	0.08, 0.28
Direct Effects	-0.08	-0.42, 0.26	0.54	0.21, 0.86
Minimum Feeding Frequency[5]				
Total Effect	-0.02	-0.42, 0.41	-0.00	-0.34, 0.36
Indirect Effects				
Food security	0.00	-0.08, 0.08	0.00	-0.08, 0.07
Nutrition knowledge	0.11	0.03, 0.20	0.13	0.04, 0.24
Direct Effects	-0.12	-0.53, 0.30	-0.13	-0.48, 0.23
Dietary Diversity Score[1]				
Total Effect	0.17	-0.10, 0.44	0.49	0.24, 0.75
Indirect Effects				
Food security	0.10	0.04, 0.19	0.10	0.04, 0.18
Nutrition knowledge	0.03	-0.02, 0.09	0.03	-0.03, 0.11
Direct Effects	0.05	-0.23, 0.32	0.37	0.10, 0.63
Portion Size, Quintile[5]				
Total Effect	0.08	-0.17, 0.33	0.33	0.10, 0.56
Indirect Effects				
Food security	-0.03	-0.09, 0.02	-0.03	-0.09, 0.02

Nutrition knowledge	0.05	0.00, 0.11	0.06	0.00, 0.13
Direct Effects	0.06	-0.20, 0.32	0.30	0.05, 0.53
Complementary Food Consistency, Photograph[5]				
Total Effect	-0.01	-0.30, 0.30	0.26	0.00, 0.51
Indirect Effects				
Food security	-0.03	-0.09, 0.02	-0.03	-0.09, 0.02
Nutrition knowledge	0.09	0.03, 0.17	0.11	0.04, 0.19
Direct Effects	-0.07	-0.37, 0.24	0.18	-0.09, 0.45
Energy Intake from Complementary Foods[1]				
Total Effect	-53.3	-105.1, -0.9	26.2	-24.3, 78.2
Indirect Effects				
Food security	-3.0	-15.1, 6.7	-3.1	-14.4, 7.2
Nutrition knowledge	10.9	1.4, 25.0	13.0	1.3, 27.6
Direct Effects	-61.2	-113.5, -9.5	16.4	-34.9, 69.2
Category of Vitamin A Intake[5]				
Total Effect	0.06	-0.19, 0.32	0.17	-0.08, 0.41
Indirect Effects				
Food security	0.04	-0.01, 0.10	0.04	-0.01, 0.10
Nutrition knowledge	0.01	-0.04, 0.07	0.01	-0.05, 0.08
Direct Effects	0.01	-0.24, 0.28	0.12	-0.13, 0.37

[1]Estimates are linear regression coefficients

[2]Food Insecurity Experience Scale raw score [28] subtracted from 8

[3]Nutrition knowledge score is an additive score based on the number of correct responses to questions about vitamin A and infant and young child feeding recommendations; see Supplemental Table 6-1

[4]Complementary Feeding Index is an additive score based on feeding frequency, dietary diversity, complementary food thickness, and portion size; see Table 6-1

[5]Estimates are probit regression coefficients

Supplemental Table 6-1. Nutrition knowledge questions and scoring.

Domain	Indicator Questions / Responses		Scoring	Domain Weight
Healthy growth (4 points possible)				2
	What makes a child grow well? (open ended)			
		Mentioned breastfeeding	+1	
		Mentioned giving enough food	+1	
		Mentioned giving a variety of foods	+1	
		Mentioned child not getting sick often	+1	
Vitamin A (6 points possible)[1]				3
	Have you ever heard of vitamin A?			
		Yes	+1	
		No / Don't know	+0	
	Why is vitamin A important (open ended)			
		Prevents disease / diarrhea	+1	
		For healthy eyes and vision	+1	
		Don't know	+0	
	Can you name 3 sources of vitamin A?		+1 per correct response	
Colostrum (1 point possible)				1
	Is it good or bad to give the first milk (colostrum)?			
		Good	+1	
		Bad or Don't know	+0	
Timely introduction of diverse complementary foods (24 points possible)				2
	At what age should a child first be given [list of 12 foods]?[2]			
		6 months	+2	
		7 or 8 months	+1	
		<6 or >8 months	+0	
Timely introduction of thick complementary foods (2 points possible)				2
	At what age should a child be given thick porridge like this [show photograph]			
		6 months	+2	
		7 or 8 months	+1	
		<6 or >8 months	+0	
Meal Frequency (3 points possible)				2
	How many times per day should 6 to 8 months old children be fed?			
		2 or more times	+1	

Less than 2 or Don't know	+0	
How many times per day should 9 to 11 months old children be fed?		
3 or more times	+1	
Less than 2 or Don't know	+0	
How many times per day should 12 to 23 months old children be fed?		
3 or more times	+1	
Less than 2 or Don't know	+0	
Portion Size (6 points possible)		2
How many buna cups should a 6 to 8 months old child be fed per meal?		
3 or more buna cups	+2	
2 buna cups	+1	
1 buna cup or less	+0	
How many buna cups should a 9 to 11 months old child be fed per meal?		
3 or more buna cups	+2	
2 buna cups	+1	
1 buna cup or less	+0	
How many buna cups should a 12o 23 months old child be fed per meal?		
3 or more buna cups	+2	
2 buna cups	+1	
1 buna cup or less	+0	

[1]Vitamin A domain excluded from the baseline nutrition knowledge score

[2]Foods listed are: water, porridge/gruel, avocado, haricot beans, sweetpotato, egg, mango, cow's milk, goat meat, kale, chicken, and lentils

Supplemental Table 6-2. Comparison of households lost to follow-up with those not lost to follow-up.

	Not Lost to Follow-up n = 548	**Lost to Follow-Up** n = 57	**p-value**
Intervention Group			
Control (%)	42.9	59.7	0.08
Partial Intervention (%)	26.1	19.3	
Full Intervention (%)	31.0	21.1	
Household sociodemographic characteristics			
Woreda			
Aleta Chuko (%)	40.9	35.1	0.39
Dila Zuria (%)	39.6	49.1	
Gedeo (%)	19.5	15.8	
Caregiver age, years[1]	26.1 ± 5.2	26.0 ± 5.7	0.95
Caregiver minimum dietary diversity (%)	16.4	12.3	0.38
Caregiver number of food groups[2]	3.2 ± 1.5	3.0 ± 1.4	0.49
Household size[1]	5.6 ± 2.1	5.3 ± 2.0	0.29
Any off-farm income (%)	55.7	54.4	0.85
Caregiver education[2]			
Less than cycle 1 completed (%)	45.2	52.6	0.39
Cycle 1 completed (%)	36.6	28.1	
Cycle 2 completed (%)	18.1	19.3	
Wealth Index[1]	0.01 ± 0.99	-0.07 ± 1.06	0.60
Food insecurity experience scale (reverse coded)[1,3]	4.2 ± 2.9	3.9 ± 3.0	0.52
Knowledge score without vitamin A[1,4]	7.2 ± 1.6	7.3 ± 1.5	0.75
Nutritional Status			
Length-for-age z score[1]	-0.4 ± 1.4	-0.4 ± 1.8	0.83
Stunted (%)	12.9	14.0	0.81
Weight-for-age z score[1]	-0.2 ± 1.4	0.0 ± 1.8	0.49
Underweight (%)	10.0	13.0	0.53
Weight-for-length z score[1]	0.2 ± 1.7	0.3 ± 2.0	0.81
Wasted (%)	9.3	13.2	0.42
Child Characteristics			
Female (%)	49.8	42.1	0.27
Age, months[1]	2.7 ± 1.6	2.5 ± 1.6	0.54
Currently breastfed (%)	99.6	100.0	0.17
Any non-breastmilk foods or liquids in past 7 days (%)	22.1	26.3	0.48

[1]Values are means ± standard deviations

[2]Cycle 1 is defined as grades 1 through 4, cycle 2 is defined as grades 5 through 8

[3]Food Insecurity Experience Scale raw score [28] subtracted from 8

[4]Nutrition knowledge score without vitamin A is an additive score based on the number of correct responses to questions about infant and young child feeding recommendations; see Supplemental Table 6-1

[5]Values are median (25th percentile, 75th percentile)

Chapter 7 - Discussion

The goal of this dissertation was to provide a more complete characterization of complementary feeding, including identifying novel approaches to measuring complementary feeding, understanding its determinants, and achieving behavior change.

7.1 Summary of Key Results

In Chapter 4, we described novel indicators of portion size and complementary food consistency, and assessed their validity relative to energy intake from and energy density of complementary food in a sample of young children 6 to 13 months in southern Ethiopia. Caregivers' estimate of usual portion size using uncooked rice is a valid indicator of total energy intake, and of energy and amount of food consumed per feeding episode as determined by multiple-pass 24-hour dietary recall in this sample. Portion size was correlated with each of these outcomes. Despite poorer precision with increasing portion sizes, there was no evidence of systematic over- or under-estimation. The validity of using photographs as an indicator energy density is somewhat inconclusive. This approach may be more valid and informative in populations where porridges/gruels comprise a greater proportion of complementary foods than what was observed in our sample. Furthermore, low energy dense complementary foods were less common than expected, and therefore the validity of this indicator should be assessed in populations where low energy-dense complementary foods are a public health concern.

In Chapter 5, we used exploratory factor analysis (EFA) and exploratory structural equation modeling (ESEM) in an attempt to identify patterns and predictors of complementary feeding, and to explore differences between age categories. We identified both similarities and uniquenesses in factor structure among young children 6 to 8.9 months, 9 to 11.9 months, and 12 to 17.9 months. Specifically, intake of protein-rich food groups were correlated in each age category, while vitamin A-rich and other fruits and vegetables were correlated with one another and with minimum meal frequency. In children under one year of age, portion size and complementary food thickness loaded onto a factor with minimum meal frequency, but did not load in children over one year. We were able to identify several important predictors of patterns of complementary feeding. Namely, Traditional Authority (sub-districts), wealth and food insecurity were significant predictors of complementary feeding. Other predictors, such as caregiver-headed household, child age, caregiver education, and feeding a child from his or her own dish, were not consistently associated across age groups and the relevance of these potential predictors is less clear.

In Chapter 6, we evaluated potential impact pathways of the Quality Diets for Better Health (QDBH) project, a nutrition-sensitive agriculture project with an integrated complementary feeding component in southern Ethiopia. We demonstrated that the QDBH project improved household food security and nutrition knowledge, which in turn mediated modest improvements in complementary feeding practices. Specifically, nutrition knowledge mediated improved overall complementary feeding, increased portion size, thicker consistency foods, and increased energy intake, whereas food security mediated improved dietary diversity. However, the main finding of these analyses was that the intervention group receiving the "Healthy Baby Toolkit" (HBT) had improved summary complementary feeding scores, improved dietary diversity, and increased portion size that was greater in magnitude than indirect effects, was not explained by either mediator, and was not seen in the group that did not receive the tools. This supports the idea that "cues to action" are important facilitators of behavior change, consistent with the Health Belief Model by which the HBT was designed [1-3].

7.2 Limitations

A number of limitations have been discussed in each of the preceding three chapters. Here, we summarize some of the key limitations, particularly as they pertain to more than one specific aim.

Measurement Error

Our aim in Chapter 4 was to assess the validity of test indicators of portion size and consistency that could be incorporated into a large-scale survey. The reference method for this aim was a multiple-pass 24-hour dietary recall; any dietary assessment method is prone to some amount of measurement error, but there are particular concerns with multiple-pass 24-hour dietary recall when used as a reference method [4]. Namely, both multiple-pass 24-hour dietary recall and the test methods assessed in Chapter 4 rely on caregiver recall and self-report, which are potential sources of bias. While random measurement errors tend to attenuate strengths of association, the fact that both test and measurement methods are prone to the same bias means that our correlations could be biased away from the null. Furthermore, we have no reference method in the Malawi dataset against which to compare our test indicators. We therefore rely on the assumption that the indicators are valid in a sample of 6- to 17-month old children and their caregivers in Malawi based on their performance in a sample of 6- to 13-month old children and their caregivers in Ethiopia.

We developed and tested only one method of assessing portion size and one method of assessing complementary food consistency. We cannot, therefore, draw any conclusions about their performance relative to alternatives. Ideally, the process of identifying and validating indicators would include testing of alternatives and assessing interpretability by the target population, neither of which was undertaken here.

Limited Generalizability

The analytical samples used in this dissertation have limited generalizability outside of their age ranges and geographic locations. In Chapter 4, we assess the relative validity of indicators of portion size and complementary food consistency among young children 6 to 13 months, a narrow age range compared to the fact that complementary feeding extends up to 24 months. Additionally, we found that the precision of portion size estimates decreases with increasing portion size. Because portion sizes are likely to increase with age, we can draw no conclusions about the validity of portion size estimates in older populations, and on the contrary, there is reason to question whether the indicators would perform well in older ages. The indicator of complementary food consistency was weakly correlated with complementary food energy density; the correlation was somewhat higher when restricted only to the energy density of porridges. Contrary to expectation, low energy dense foods were uncommon in this sample. It is possible that the indicator would be more relevant in samples where low energy dense foods and/or porridges are more common.

In Chapter 6, we assessed the impact of the Quality Diets for Better Health (QDBH) project using the same sample as used in Chapter 4. Thus, the same concerns are true for the sample of narrow age range. However, an additional concern with the impact evaluation is that only *kebeles* that had the highest potential for orange-fleshed sweet potato (OFSP) growth – for example were at lower altitude – and had an absence of extraneous nutrition programs were eligible for this impact evaluation study. These eligibility criteria are likely to confer the greatest potential for impact. The project may be less impactful in *kebeles* with less amenable growing conditions, or where other nutrition programs are operating.

The patterns of complementary feeding practices that were observed in Chapter 5 were not hypothesized, but rather were data-driven. The predictors, largely, support the idea of limited reproducibility of the findings, as it was sub-region that was most strongly and consistently associated with the extracted factors. However, the method of applying EFA to complementary feeding indicators may be relevant to others seeking to identify patterns of complementary feeding practices.

Potential Social Desirability Bias

A final limitation is the potential for social desirability bias, particularly in Chapters 4 and 6. In Chapter 4, we observed that the correlations between estimated portion size and total complementary food energy intake, average energy per feeding episode, and average amount of food consumed per feeding episode significantly differed by intervention group. Specifically, the full intervention – the group that received tangible tools to promote age-appropriate portion size and thicker consistency foods – had stronger correlations, while the partial intervention – the group that received some nutrition education about these recommendations but no tangible tools – had weaker correlations. We cannot know the reason for the difference, but it is possible that caregivers in the full intervention group reported systematically biased estimates both for estimated portion size and in the multiple-pass 24-hour dietary recall. Similarly, there is potential for social desirability bias in the impact assessment reported in Chapter 6. Alive and Thrive, a nutrition-specific project that aims to improve complementary feeding and other nutrition outcomes, was implemented in the same region several years prior to QDBH. In their program evaluation, they tabulated a social desirability score, and found no evidence of social desirability bias [5]; however, we cannot eliminate the possibility in our sample.

7.3 Strengths and Innovation

Despite the aforementioned limitations, there are also strengths of this dissertation. Foremost strengths are that the research presented in this dissertation use novel methods to address several knowledge gaps.

The availability of valid indicators to assess a practice enables researchers and program evaluators to surveil, identify vulnerable populations, research predictors and/or outcomes, and evaluate programs that aim to change behavior. The as-yet lack of methods to assess usual portion size and complementary food consistency means very little is known about these practices. We have introduced new methods that can be incorporated into surveys, and while the validity of the complementary food consistency indicator is unclear, we have demonstrated that portion size is correlated with complementary food and energy intake, and is predictive of low complementary food energy intake as determined by multiple-pass 24-hour dietary recall. We have also assessed these correlations in several sub-groups in order to assess which conditions might impact the validity of the indicator. The use of survey-based indicators has several practical advantages of 24-hour dietary recall and weighed food records: they require considerably less training time for data collectors, far fewer materials, and interview time/respondent burden are much lower for indicators than for 24-hour dietary recall. These advantages translate into cost savings for an organization aiming to assess infant and young child diets.

In Chapter 5, we have described an approach to analyze complementary feeding practices that is considerate of the fact that complementary feeding practices are not independent of one another. In particular, in our analytical sample, we demonstrated that indicators of food group consumption, minimum meal frequency, portion size, and consistency tend to positively correlate, though portion size and consistency did not load onto any latent factor in children over one year. This finding supports the hypothesis from Arimond and Ruel that feeding practices are likely to cluster [6]. In this sample, it was behavioral determinants in the "opportunity" domain – sub-region, household food insecurity, and wealth – that influenced complementary feeding most consistently. The impact of other factors, including individual-level factors like caregiver education and child illness – was not consistently associated with complementary feeding.

Lastly, the findings in Chapter 6 elucidate pathways by which nutrition-sensitive agriculture projects may achieve impacts on complementary feeding outcomes. Improved caregiver knowledge of complementary feeding recommendations is a pathway to improve complementary feeding practices, though effect sizes may be small. This is consistent with previous work by de Brauw *et al.* [7]. However, we elaborated by also demonstrating the impact of an OFSP promotion program on household food security, and demonstrating the improved food security mediates improved diversity of young child diets. The analyses in Chapter 6 also show the added benefit of the HBT, in what has been the most rigorous quantitative impact evaluation on the HBT to date. The HBT is, in its own right, an innovative strategy for promoting optimal complementary feeding, and we have presented evidence that the HBT may be responsible for the greatest magnitude improvements.

7.4 Public Health Implications

The findings presented in this dissertation have implications for academic, governmental, and non-governmental organizations. The *Guiding Principles for Complementary Feeding of the Breastfed Child* provide evidence-based recommendations for multiple dimensions of complementary feeding and should be followed [8]. However, given that current indicators for

IYCF are limited in their scope, there is risk of programs neglecting complementary feeding practices that may not be captured by impact evaluations. We have introduced tools that could be incorporated into surveys. While they should not be expected to replace more rigorous evaluation, the only current IYCF indicator of complementary food energy intake is feeding frequency. As a result, continued attempts to assess the relationship between individual IYCF indicators and nutritional status are likely oversimplified and misleading. In conducting research on complementary feeding and in implementing programs to address complementary feeding, researchers and program implementers, respectively, should consider the multi-dimensionality of complementary feeding and not be deterred by lack of methods of assessment. Researchers, in particular, should consider utilizing methods that are more suitable to the complexity of complementary feeding. We have demonstrated that EFA may be one approach.

7.5 Future Directions

The findings presented in this dissertation warrant further study of portion size and complementary food consistency indicators that can be incorporated into surveys. The importance of developing and validating indicators of energy intake from complementary foods has been identified by others [9] and should be considered a research priority. If a robust research budget were available, the validity of the indicators described in Chapter 4 – and potentially the validity of alternative indicators of portion size and consistency – should be assessed in additional samples. These samples should include children ranging the full spectrum of complementary feeding – from 6 to 23.9 months. Further, samples should be taken from multiple countries in Africa, Asia, and Latin America. These countries should be strategically selected for their diversity in complementary feeding norms. To name a few examples, validation should be assessed in countries with different staple crops (for example, maize, wheat, and rice);

where feeding with and without spoons, bottle, or other utensils are the norm; where a majority of complementary foods are prepared at home and also away from home; and in countries experiencing the nutrition transition as well as those with more traditional diets. Samples in each country should include households in both urban and rural settings, and ideally should include sufficient sample size to be able to assess breastfed and non-breastfed children separately, as well as other potentially relevant sub-groups. The indicators should be validated against "gold standard" reference methods such as weighed food records and/or doubly labeled water that are note prone to recall bias; weighed food records have the advantage of being able to estimate micro- and macronutrient intakes as well.

Further, there remain several dimensions of complementary feeding for which there are no indicators, including responsive feeding, and food safety/hygiene. There may be additional approaches for characterizing complementary feeding patterns as a whole. Latent class analysis, which groups *individuals* based on the sameness of their response patterns, may be useful. It could also be useful to assess which approach accounts for more variation in outcomes of interest – such as nutritional status or developmental indicators.

The HBT enhanced the QDBH project, a nutrition-sensitive agriculture project that promotes orange-fleshed sweet potato agriculture and consumption. Since the follow-up survey included in this dissertation, one additional follow-up survey was conducted in a food secure season, in which similar outcomes were assessed. A similar mediation analysis may provide insight on the sustainability of the behavior change, and how the impact might differ in a food secure season. Furthermore it will be useful to assess the impact of the intervention and HBT on other, secondary outcomes such as morbidity and nutritional status. Lastly, it would be useful to assess the addition of the HBT, or other cues to action, in the context of other nutrition-sensitive programs to identify platforms for delivery.

7.6 Conclusions

Complementary feeding is a behavior; in a sense, it is a relationship between two or more people. It is complicated to measure, understand drivers of, and change, particularly when measurement tools and our understanding of drivers are lacking. The research presented in this dissertation acknowledges that current approaches are sometimes inadequate, and aims to introduce approaches that may be more useful moving forward. Advancing our knowledge of complementary feeding and our ability to implement evidence-based practices requires valid instruments for assessing complementary feeding. Adequate resource allocation should be a priority for nutrition scientists – both in terms of improving current instruments for complementary feeding assessment and for achieving behavior change that is paramount if meaningful improvements in child nutritional status are to be realized.

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