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Hum Nat
DOI 10.1007/s12110-015-9239-2

Fetal Protection

The Roles of Social Learning and Innate Food Aversions in South India

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Abstract Pregnancy involves puzzling aversions to nutritious foods. Although studies generally support the hypotheses that such aversions are evolved mechanisms to protect the fetus from toxins and/or pathogens, other factors, such as resource scarcity and psychological distress, have not been investigated as often. In addition, many studies have focused on populations with high-quality diets and low infectious disease burden, conditions that diverge from the putative evolutionary environment favoring fetal protection mechanisms. This study tests the fetal protection, resource scarcity, and psychological distress hypotheses of food aversions in a resource-constrained population with high infectious disease burden. The role of culture is also explored. In the first of two studies in Tamil Nadu, India, we investigated cultural explanations of pregnancy diet among non-pregnant women ($N=54$). In the second study, we conducted structured interviews with pregnant women ($N=94$) to determine their cravings and aversions, resource scarcity, indices of pathogen exposure, immune activation, psychological distress, and emic causes of aversions. Study 1 found that fruits were the most commonly reported food that pregnant women should avoid because of their harmful effects on infants. Study 2 found modest support for the fetal protection hypothesis for food aversions. It also found that pregnant women most commonly avoided fruits as well as "black" and "hot" foods. Aversions were primarily acquired through learning and focused on protecting the infant from harm. Our findings provide modest support for the fetal protection hypothesis and surprisingly strong support for the influence of cultural norms and learning on dietary aversions in pregnancy.

Electronic supplementary material The online version of this article (doi:10.1007/s12110-015-9239-2) contains supplementary material, which is available to authorized users.

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Published online: 19 August 2015

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Keywords Pregnancy · Aversions · Cravings · Fetal protection · Social learning · Individual learning

Pregnancy increases energetic demands on the mother and alters her immune function. It also involves puzzling changes, such as significant shifts in dietary preferences, and nausea and vomiting (Fessler 2002; Flaxman and Sherman 2000; Hook 1976; McKerracher et al. 2015; Profet 1988; Young 2010). These changes are widespread across populations, suggesting possible evolutionary functions. Food aversions and cravings, specifically, have been documented in approximately 66% of populations and, within populations, have occurred in up to 92% of individuals (Flaxman and Sherman 2000; Young and Pike 2012). Studies have shown that in many cultures pregnant women typically avoid meats, vegetables, and bitter-tasting foods and crave foods high in Vitamin C, such as sour-tasting unripe fruit (Fessler 2002; Flaxman and Sherman 2000; Geissler et al. 1999; Hook 1976; Profet 1988; Tierson et al. 1985; Wijewardene et al. 1994; Young et al. 2010).

From an evolutionary perspective, dietary shifts in pregnancy are hypothesized to reduce exposure to toxins and pathogens (Hook 1976; Fessler 2002; Flaxman and Sherman 2000; Profet 1988) or diversify nutrient intake (Coronios-Vargas et al. 1992). Hook (1976) and Profet (1988) emphasized the risk that plant teratogens, which evolved to disrupt cellular signaling in plant consumers, posed to the developing fetus. If consumed during organogenesis (first trimester), these compounds could cause miscarriage or birth defects (Profet 1988). Later, researchers emphasized that consuming meat-borne pathogens could also be detrimental to the pregnant woman (Fessler 2002; Flaxman and Sherman 2000), especially during the first trimester when cell-mediated immunity is down-regulated to support implantation (Abrams and Miller 2011; Mor and Cardenas 2010; but see Kraus et al. 2012; Pazos et al. 2012; Racicot et al. 2014). Since women's capacity to mount an immune response is altered, an increase in nausea and vomiting (NVP) and aversions to pathogenic foods serve as mechanisms for fetal protection (Fessler 2002; Flaxman and Sherman 2000). Cravings for fruits, however, should increase given their high levels of Vitamin C, carbohydrates, and protection against teratogens (Fessler 2002). These dietary shifts are hypothesized to be innate: most pregnant women in most populations will experience them in response to common food categories that are particularly harmful or helpful to the developing fetus.

Tests of these hypotheses, while generally supportive, have also indicated that other factors are involved. Recent studies, for example, have found variation in the types of foods that are craved, avoided, and consumed (Patil 2012; Young and Pike 2012). Some researchers hypothesize that dietary shifts in pregnancy are evolved strategies to diversify food intake rather than avoid toxic foods (Coronios-Vargas et al. 1992; Demissie et al. 1998). As a result, women might feel averse to foods that they consume on a daily basis, which ultimately signals the need to diversify intake. In addition, most of the research investigating fetal protection has focused on resource-rich populations (Patil 2012) with low infectious disease burden. A study in a food-constrained population found that pregnant women were more likely to crave meat, a highly nutritious but limited food, and avoid "harmless" staple foods, such as cereals and grains (Young and Pike 2012).

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Dietary shifts in pregnancy could also be responsive to variation in resource availability, such as food insecurity (Patil 2012; Placek and Hagen 2013; Steinmetz et al. 2012; Young and Pike 2012). Young and Pike (2012), for example, found that 92% of pregnant Turkana women and 47% of pregnant Datoga women in East Africa reported food aversions to maize, a non-traditional relief food, but nevertheless showed high rates of consumption owing to reduced availability of other foods. Women in this study mentioned that consuming the nontraditional foods did not satisfy their appetite and was the cause of smaller babies at birth (Young and Pike 2012). Nichter and Nichter (1983) suggested that food scarcity, in addition to cultural factors linked to humoral theory, played a role in Indian women "eating down" during pregnancy. Resource scarcity can also lead to the craving and consumption of non-food items, such as mud, or other types of pica substances (Laufer 1930; Placek and Hagen 2013). Despite this link between resource scarcity and dietary shifts in pregnancy, most of the research focusing on food cravings and aversions has been with populations that do not suffer from food insecurity (Patil 2012).

A few studies have found that psychological distress is also associated with dietary preferences (Marcus and Heringhausen 2009). In one study of Aboriginal women with gestational diabetes, study participants reported cravings for junk food and frequent bingeing and purging to cope with anxiety and depression (Neufeld 2011). Research has also found a positive association between psychological distress and pica in pregnancy (Placek and Hagen 2013).

Cultural beliefs and attitudes play an important role in the expression, timing, and type of dietary changes that occur during gestation and other life stages (Laderman 1981). Many cultures use humoral theory as a classification system to determine which foods are safe versus unsafe to consume during pregnancy (Foster 1953; Nag 1994). Throughout India, for instance, pregnant women avoid "hot" foods (e.g., mango, pineapple, jackfruit, and papaya) to prevent abortion (Nag 1994). According to humoral theory, pregnancy is considered a "hot" state in which women need cooling foods to bring balance to the body (e.g., wheat and rice are considered cooling in Gujarat, India; Nag 1994). Pregnancy-specific food taboos are also common. For example, the Semai horticulturalists of Southeast Asia avoid specific foods in pregnancy, such as certain bird and rodent species, because they believe these items could lead to crying and diarrhea in the newborn (Dentan 1966).

Satisfying pregnant women's dietary desires also varies across cultures. In Iran, for example, one informant reported that pregnant women are refused "special" treatment and extra food in pregnancy, even though women often experience strong cravings for meat, sweets, sour foods, and soil (Freidl 1997). In contrast, a study conducted in Puerto Rico found that cravings in pregnancy must be fulfilled in order to prevent miscarriage (Steward 1956). Other cultures perform rituals late in pregnancy to ensure that the pregnant woman's desires (and those of the unborn fetus) have been gratified (Bhattacharyya 1981; Petitet and Vellore 2007).

The Current Studies

The aim of the current research was to investigate pregnancy cravings and aversions in a resource-constrained population with a high burden of infectious disease: Tamil

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Nadu, India. Specifically, we investigated cultural models of food cravings and avoidances in pregnancy and tested the fetal protection (pathogens/toxins or pathogen-specific), resource scarcity, and psychological distress hypotheses for food aversions among pregnant women. Theoretical models of food cravings will be analyzed in a future publication. The Washington State University Institutional Review Board approved both studies.

Study Population

The research took place during eight weeks in the summer of 2012. The study sites included 13 rural villages outside Tiruvannamalai district, Tamil Nadu, India (12°N, 79°E), with an estimated population of 13,000. In this region, villagers primarily speak Tamil, with some knowledge of English. In this agricultural community, farmers harvest rice and groundnuts. Although these foods constitute a large portion of the diet, villagers also consume milk, eggs, chicken, and various dhals and curries. Some staple foods are only seasonally available. During the time of the study, rice, mangoes, and groundnuts were in abundance, along with black grapes, banana, apple, and, to a lesser extent, papaya.

India is a region of high food insecurity, with more than 32% of the population living below $1 per day and 17.5% living below the minimum requirements for dietary energy consumption (WHO 2015). The proportion of individuals in India who were undernourished in 2012–2014 was 15.2%, compared with 11.3% worldwide (FAO 2015). One study conducted in Vellore, Tamil Nadu (135 km from study location) found that three-quarters of the study sample was food insecure (Gopichandran et al. 2010).

Burden of disease in India is also high because a large portion of the population is living in poverty (Aparajita and Ramanakumar 2005). According to the World Health Organization, 41% of Indian deaths in 2012 were due to communicable disease (WHO 2015), whereas the global average was 24.9% in 2010 (Lozano et al. 2013).

Pregnancy in this region of Tamil Nadu is culturally defined as a period of increased heat in the body, intense cravings, compulsions, and desires (*acai*) (e.g., Van Hollen 2003). To satisfy acai, pregnant women participate in religious ritual and follow strict dietary guidelines regarding specific fruits and a variety of rice dishes, such as tamarind rice and tomato rice. Husbands and other family members are largely responsible for satisfying the pregnant woman's acai in order to reduce potential problems during delivery and enhance the emotional well-being of the mother and infant (Van Hollen 2003). Pregnant women in Tamil Nadu typically avoid the following "hot" foods: papaya, pineapple, mango, jackfruit, groundnuts, eggplant, and potatoes; consumption of "cold" foods, which include milk, yogurt, banana, and coconut, is encouraged (Nag 1994). (Note that "heat" does not refer to actual temperature, pungency, or spiciness.)

Study 1: Cultural Investigation of Avoidances and Cravings

The goal of Study 1 was to generate a list of common food cravings and avoidances in pregnancy in this population, and to identify emic explanations of such avoidances. The

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data gathered in this part of the investigation were used to inform Study 2 (see Placek and Hagen 2013 for more details on the study methods, and for results regarding "non-food" cravings, i.e., pica and amylophagy).

Participants

Participants were non-pregnant adult women located in five villages (n=54). The first author (CDP) and a woman translator used convenience sampling, going door-to-door to recruit participants. The goal of this portion of the study was simply to identify common cravings and avoidances during pregnancy. Participants were compensated with an amount in accordance to local norms (a gift of food). After providing informed consent, participants were asked to free-list (Quinlan 2005) "foods commonly avoided in pregnancy" and "foods commonly craved in pregnancy" and to report potential health consequences if women consumed the reported "taboo" items. Women in this part of the study were not asked about their personal avoidances and cravings; however, they occasionally provided information about past pregnancies (results not reported here).

Analysis

First, food avoidances and cravings were recoded into general descriptive food categories obtained in an earlier study by Flaxman and Sherman (2000). These categories were meat, non-alcoholic beverages, vegetables, alcoholic beverages, "ethnic, strong, and spicy" (ESS), dairy/ice cream, sweets, grains/starches, and fruit. An additional category ("sour") was added because women commonly mentioned this as a pregnancy craving without reference to a specific food. Percentages were calculated for each category to determine the most commonly avoided food group. Next, reasons for avoiding each food were tabulated to determine emic health consequences of consuming these items.

Study 1 Results

The average age of women respondents was 38.3 (range: 19–80). After combining related foods into categories, we found that fruits were the most commonly mentioned avoided food, followed by ESS foods and meat (Table 1). The remaining food groups were reported at a rate below 6%. Within the fruit category, naval (*Syzygium cumini*) was mentioned most often (39%), followed by papaya (26%) and black grapes (24%). In the ESS group, sesame was the only listed item. The meat group varied considerably; some participants mentioned chicken, whereas others did not specify that any particular meat was harmful. Participants reported that pregnant women were most likely to crave "sour" foods, followed by ESS, fruits, and vegetables. Six women did not mention a specific food; instead, they stated that women's cravings usually vary based on desire, or acai. See Table 1 for frequencies and percentages of food avoidances and cravings.

Participants were asked why each food is to be avoided during pregnancy. Results are presented for the most frequently mentioned food items: papaya,

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Table 1 Number (%) of women in study 1 who stated that this food category is avoided or craved

Etic category	Avoidances	Cravings
Fruit	35 (64.8)	16 (30)
Ethnic, strong, and spicy (ESS)	12 (22.2)	17 (31)
Meat	6 (11.1)	3 (5.7)
Vegetables	3 (5.7)	10 (30)
Sweets	3 (5.7)	3 (5.7)
Non-alcoholic beverages	2 (3.7)	0
Grains and starches	1 (1.9)	6 (11.1)
Dairy/ice cream	1 (1.9)	0
"Sour"	0	26 (48)
Alcoholic beverages	0	0

naval (Indian blackberry; *Syzygium cumini*), black grapes, sesame, and meat (Table 2). Participants were not asked why pregnant women craved specific substances.

These findings reveal that the foods that are most commonly avoided are "hot" foods, such as papaya, and "black" foods, such as naval, black grapes, and sesame. These items are commonly avoided in South India owing to the perception that they cause harm to the fetus (Nag 1994). The danger of "hot" foods is based primarily on humoral theory: consuming these items can cause increased heat in the body, leading to a miscarriage (Nag 1994). "Black" foods lead to infants with dark skin or black patches (known as *thirutu or manthai* in Tamil; Engelin 2009; Placek and Hagen 2013).

Table 2 Reasons to avoid foods in pregnancy, and the percent of women in study 1 who mentioned each reason

Food item	Reason to avoid in pregnancy	%
Papaya	Abortion	53
	Thirutu/Manthai	27
	"Disease"	13
	Not sure	7
Naval	*Thirutu/Manthai*	73
	"Disease"	27
Black grapes	*Thirutu/Manthai*	92
	"Disease"	8
Sesame	*Thirutu/Manthai*	82
	Abortion	18
Meat	Abortion	40
	Heat in the body	50
	Thirutu/Manthai	10

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Study 2: Pregnancy Aversions and Cravings

The second study used a cross-sectional design and structured interviews to test five hypotheses for dietary aversions in pregnant women: fetal protection (toxins or pathogens), fetal protection (pathogen-specific), resource scarcity, psychological distress, and socioeconomic factors. This study also explored aversions to the emic food categories that were identified in Study 1.

Participants

Ninety-five pregnant women were recruited from several Primary Health Centers (PHCs) in the villages. Women in Tamil Nadu are given a substantial monetary incentive (about US $200) to register with the PHCs when they become pregnant; therefore, this sample is likely representative of the general population of pregnant women who live in villages in Tiruvannamalai. All pregnant women who registered with PHCs in the study region were included regardless of trimester.

Methods

Pregnant women completed a structured questionnaire that included demographic information and measures of food insecurity and psychological distress (see the Appendix in the ESM). They were also asked to free-list any food cravings or aversions they had experienced during pregnancy. For each avoided food, we also recorded the reason that food was avoided (e.g., vomiting, stomach problem). In addition, we measured skinfold thicknesses at the tricep and bicep, and height and weight.

Outcome Variables

Food cravings and aversions: For each food for each participant, cravings and aversions were coded as follows: −1 (aversion), 0 (neither craved nor avoided), and 1 (craved).

We then aggregated foods into etic food categories based on a scheme from Flaxman and Sherman (2000) (see Table S1 in the ESM). These included fruits, meat, non-alcoholic beverages, vegetables, alcoholic beverages, "ethnic, strong, and spicy" foods (ESS), dairy/ice cream, sweets, and grains/starches. Etic categories were mutually exclusive: each food mentioned by participants was assigned to only one category. The following foods could not be assigned to any etic category: black, sesame, salt, spice, oily foods, sour, leftovers.

For each etic category, we determined whether each participant craved or avoided any food in the category. If a participant craved any food in a category, her craving score for that category was 1; otherwise it was 0. Similarly, if a participant avoided any food in a category, her avoidance score for that category was 1; otherwise it was 0. For example, chicken, fish, and unspecified "meat" were all in the "meat" category. A woman who craved chicken and "meat," but avoided fish, was scored as having both a meat craving (meat craving=1) *and* a meat aversion (meat aversion=1). A woman who neither craved nor avoided any meat had 0 for both scores (meat craving=0; meat aversion=0).

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Based on results from Study 1, and responses of participants in Study 2, we also aggregated foods into two emic food categories. The first was foods described as "hot" (which does not refer to temperature or spiciness). We added foods to this category if at least two participants rated the food as causing "heat" and if we could find independent support in the ethnographic literature on diet in Tamil Nadu that a food was considered "hot." "Hot" foods were fruits and meats (*manga*/unripe mango, mango, papaya, pineapple, palm kilangu, eggplant, chicken, and fish). The second was "black" foods, which consisted of black grapes, unspecified "black" foods, kala, and naval. These foods did not cause heat but were considered to cause black skin or black patches on the infant. Note that the emic categories overlapped with the etic categories. We then computed craving and aversion scores as described above for the etic categories.

Predictor Variables

The aim of Study 2 was to predict the presence or absence of aversions to each food category using the following models.

Fetal Protection (pathogens and toxins): Food aversions early in pregnancy are hypothesized to protect the fetus from plant toxins (Hook 1976; Profet 1988) or pathogens (Fessler 2002; Flaxman and Sherman 2000). Hence, month of pregnancy, self-reported nausea and vomiting, an index of pathogen exposure, and an index of immune activation should predict aversion to foods, such as vegetables and meat, that could harbor toxins or pathogens. Number of household members was our index of exposure to infectious pathogens (McDade et al. 2009). Previous studies have used household size as an indicator of infection risk and have found that it is a critical factor in disease transmission, especially among infants and children (Bhat and Manjunath 2013; Kristensen and Olsen 2006). Number of tetanus-toxoid vaccinations received during pregnancy was our index of immunological activation. Women in the study region receive anywhere between zero and three vaccines during pregnancy, depending on immunization history and number of pregnancies. Studies with both human and non-human subjects have used immunological activation with vaccines to examine subsequent changes in growth, reproductive effort, and diet (Bonneaud et al. 2004; Ekblom et al. 2005; Placek and Hagen 2013; Soler et al. 2003).

Fetal Protection (pathogen-specific): This model was similar to the previous model, except that it included only predictor variables that were specific to pathogen risk: month of pregnancy, number of household members, and number of vaccinations.

Resource Scarcity Hypothesis Food insecurity and anthropometric indices of low nutrition will predict decreased aversions. Food scarcity was measured with the short-form food insecurity measure, which assesses one's access to sufficient foods and has been shown to be both reliable and valid (Blumberg et al. 1999). Other variables included BMI and bicep and tricep skinfold thicknesses, which index levels of body fat.

Psychological Distress Previous research with the current study's population found that psychological distress was associated with consumption of pica substances (Placek

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and Hagen 2013). We therefore hypothesized that symptoms of psychological distress, such as depression, hopelessness, anxiety, and lethargy, would increase avoidance of potentially harmful foods. Psychological distress was measured with the Kessler-6 (K-6). The K-6 is a six-item measure that assesses serious mental illness (symptoms of anxiety and depression) in World Health Organization surveys (Kessler et al. 2010). Measures tested in India have demonstrated adequate internal consistency (Patel et al. 2008). Other research shows that this measure is an excellent diagnostic tool for depression (Cairney et al. 2007).

Socioeconomic Model Previous research has found that dietary aversions in pregnancy were associated with age, income, and education (Drewnowski 1997; Randall 1982). Our socioeconomic model for the current study included age, income, and education.

Analysis

We first used hierarchical cluster analysis to determine if food items and participants formed meaningful subgroups—in other words, whether foods showed similar patterns of cravings and aversions across our sample, and whether women had similar patterns of cravings and aversions across all the foods.

We then used logistic regression to test five a priori hypotheses for the presence or absence of food aversions: fetal protection (pathogens or toxins), fetal protection (pathogen-specific), resource scarcity, psychological distress, and the socioeconomic model. The logistic regression models were ranked by the corrected Akaike information criterion (AICc). This required each model to be fit to the same data, but our measure for income had three missing values. We imputed the values with median income, a more representative value than the mean (a few high values of income were not characteristic of the entire sample). Based on inspection of the data, as well as existing literature that emphasized the importance of pathogen threat for immunosuppressed mothers in the first trimester (e.g., Fessler 2002; Flaxman and Sherman 2000), we also included a post hoc exploratory model that only included trimester and our index of pathogen exposure (number of household family members), which were particularly strong predictors.

Statistical analyses were conducted with R version 3.1.0 (2014-04-10) for Macintosh.

Study 2 Results

Table 3 displays the descriptive statistics for predictor variables. Food insecurity was common: according to the recommended thresholds (Blumberg et al. 1999), 42.6% were food insecure, almost half of those (19.1%) with hunger. Most women also experienced nausea (63.8%) and/or vomiting (77.7%).

Fifty-one unique food items were listed as craved and/or avoided. One woman reported feeling averse to all food items, and she was therefore excluded from all analyses. 59.6% of women reported an aversion to at least one food item, and 51.1% reported a craving. The most frequently mentioned aversions were black grapes (10.6%), unripe mango (9.57%), eggplant (8.51%), and papaya (7.45%). The most

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Table 3 Summary statistics of study 2 variables

Variable	N	Min	Max	Median	Mean	SD
Age	94	19.0	35.0	23.0	23.3	3.1
Education (years)	94	0.0	18.0	10.0	9.2	3.7
Income (rupees/month)	94	500.0	50000.0	5000.0	6329.8	8259.7
Number in household	94	2.0	10.0	4.5	5.0	2.0
Parity	94	0.0	3.0	1.0	0.8	0.9
Months pregnant	94	2.0	9.0	7.0	6.4	2.0
K-6 score	94	6.0	17.0	9.0	9.8	2.6
Food insecurity score	94	0.0	13.0	1.0	2.4	3.1
Height (cm)	94	134.6	164.6	152.4	152.3	6.2
Weight (kg)	94	30.6	81.7	52.0	52.6	8.7
BMI	94	15.2	31.8	22.1	22.7	3.7
Tricep (mm)	94	5.0	24.0	12.0	13.0	4.3
Bicep (mm)	94	3.0	21.0	7.0	8.3	3.8
Number of vaccinations	94	0.0	3.0	1.0	1.2	0.8

common cravings were for greens (11.7%), tamarind rice (6.38%) mango (5.32%), and biryani (4.26%). Table S1 presents the free-listed foods craved or avoided by women in the current study, along with the number of women who craved or avoided each item.

Figure 1 shows the results of a hierarchical cluster analysis used to analyze dietary cravings for and aversions to individual food items. Vectors were sequences of −1, 0, 1, indicating aversion, no aversion/craving, and craving, respectively. Row vectors were ratings of each food item across all participants, and column vectors were ratings of all food items by each participant. Distances between vectors were computed with the standard Euclidean metric, and clusters were formed using the Ward agglomeration method, which, at each step, merges clusters that minimize within-cluster variance. The heat map shows two distinct clusters of free-listed food items. The smaller, top cluster appeared to constitute an emic category of foods that women in Tamil Nadu should either avoid ("hot" foods and "black" foods) or consume to improve pregnancy outcomes. This result provided further support for our emic "black" and "hot" food categories.

Figure 2 displays the percent of participants that craved each etic and emic food category vs. the percent that avoided each category. Fruit, as a general category, was both highly craved and highly avoided. Specific fruits were either craved or avoided (not both), with the exception of mango, which was craved by 5 women and avoided by 5 women. Because the explanation(s) for cravings differ from those for aversions, we restrict our remaining analyses to aversions.

As can be seen in Fig. 2, half of the food categories were rarely avoided by study participants. In particular, vegetables, bitter foods, ESS foods, and grains were only avoided by 3 women each, and sweets by 7. In contrast, meats and fruits were avoided by 11 and 37 women, respectively, and our two emic food categories, black and hot, by 17 and 35, respectively.

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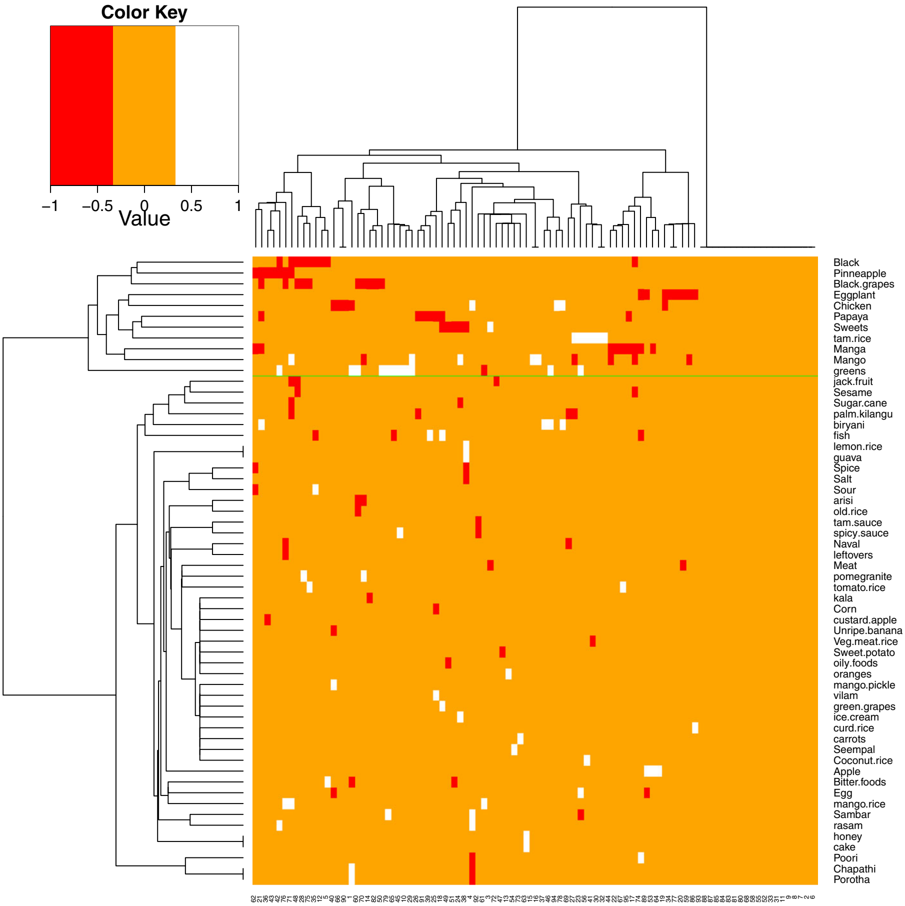

Fig. 1 Heatmap of cravings and aversions. Each column represents a participant's cravings or aversions for 51 food items. *White*: craved; shaded (*orange*): neither craved nor avoided; dark (*red*): avoided. Rows and columns were clustered with the Euclidean metric and Ward agglomeration method (see text for more details). Horizontal (green) line demarks the top cluster, which contains the foods belonging to the emic category of "hot" and "black" foods

Our sample size was not adequate to test models of rarely avoided foods. We therefore used logistic regression and AICc values to test and rank our a priori models of the presence/absence of aversions to the top five avoided food categories. Our a priori models only adequately predicted aversions to meat and hot foods (Table 4; see Table S6 for models of aversions to fruit and black foods).

The pathogen-specific protection hypothesis was the best a priori model of meat aversions. All coefficients were in the predicted direction. However, the confidence intervals of all coefficients were wide. Area under the Curve (AUC) is the probability that the model will assign a higher score to a randomly chosen participant who avoids a given food than a randomly chosen participant who does not avoid the food. Thus, AUC=0.50 indicates that a model does no better than chance, whereas AUC=1.0 indicates the model correctly classifies all such pairs of participants. According to AICc and AUC, our exploratory model of meat aversions out-performed our best a priori model (AUC=0.84 vs. 0.77, respectively; Table 4, model 2; Fig. 3).

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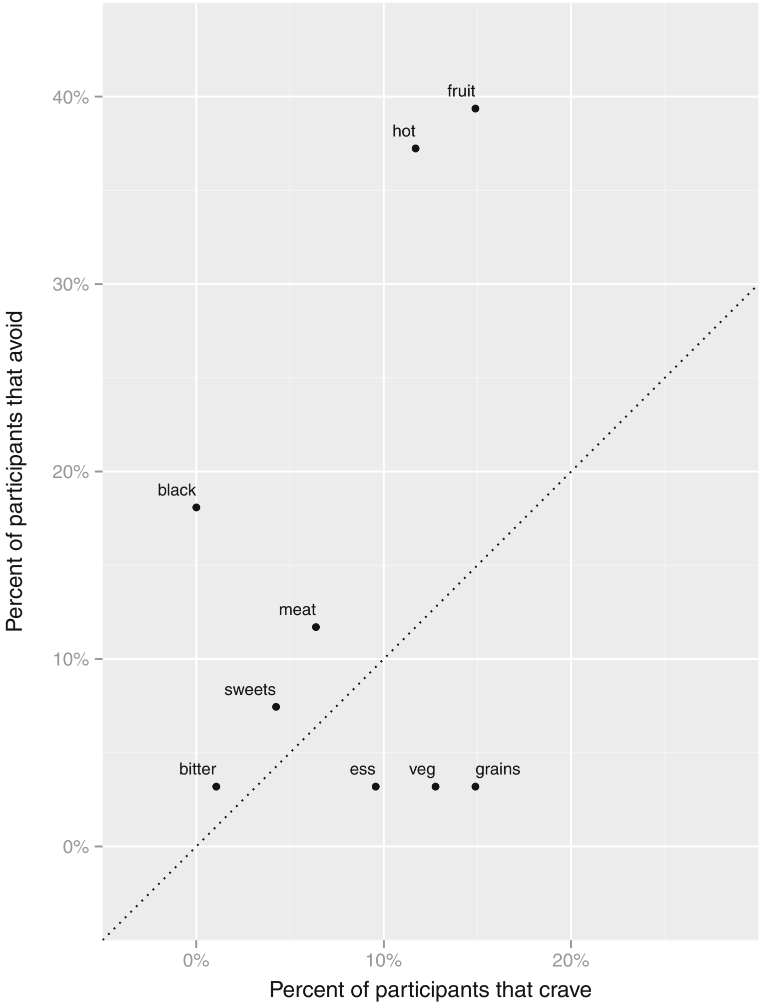

Fig. 2 Percent of participants that craved and avoided each etic and emic food category. The *dotted line* represents categories equally craved and avoided

Psychological distress was our best a priori model of aversions to hot foods (Table 4, model 3), with an AUC value of 0.65 (our exploratory model of aversions to "hot" foods peformed about as well as psychological distress; results not reported). AUC values for our best a priori models of fruit and black foods were 0.61 or less, indicating poor performance (see Table S6). Our exploratory model of these aversions also performed poorly (results not reported).

Emic Models of Food Aversions

The 56 participants who reported at least 1 food aversion were averse to 109 total foods (thus, each participant listed an average of about 2 foods). Thirty-eight unique reasons were given for aversions to these 109 foods. We aggregated these

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Table 4 Model parameters for the best AICc-ranked logistic regression models. Model 1: a priori pathogen-specific model of meat aversions; Model 2: exploratory model of meat aversions; Model 3: a priori psychological distress model of aversions to "hot" foods

	Type of aversion		
	Meat		Hot foods
	(1)	(2)	(3)
Family in house	0.48 (0.13, 0.82)	0.50 (0.15, 0.85)	
Vaccinated	0.62 (−0.55, 1.79)		
Months_preg	−0.52 (−1.00, −0.05)		
Trimester		−1.29 (−2.33, −0.25)	
Ktotal			0.20 (0.03, 0.37)
Constant	−2.39 (−5.31, 0.53)	−2.13 (−4.81, 0.54)	−2.54 (−4.30, −0.78)
Chisq	16.5	15.9	5.87
p	0.0055	0.00036	0.015
AUC (bias corrected)	0.77	0.84	0.65
Observations	94	94	94
Log likelihood	−26.60	−25.99	−59.12
Akaike inf. crit.	61.21	57.98	122.25
Residual deviance	53.21 (df=90)	51.98 (df=91)	118.25 (df=92)
Null deviance (df=93)	67.86	67.86	124.12

Diagnostic tests were conducted for each logistic regression model to test for goodness-of-fit, using a Hosmer-Lemeshow test. The Hosmer-Lemeshow χ^2 values were not significant, indicating a lack of evidence that the models were ill-fit

38 reasons in two ways. First, we combined very similar reasons: all reasons involving emic diseases and other forms of explict non-fatal harm to the fetus were coded as "fetal harm"; "heat" was left as is because heat has multiple negative consequences for the pregnancy, including abortion and stomach pain; "advice" referred to explicit mention that someone told them the food should not be eaten during pregnancy; "unknown" meant the participant could not provide a reason for avoiding that food. One woman avoided "greens" because it was "cold." Usually, "cold" foods are seen as beneficial to the pregnancy, but this woman was in her ninth month, and "cold" foods might unduly prolong the pregnancy. We therefore retained "cold." This resulted in 10 unique emic reasons for food aversions (Table 5).

Second, we coded each reason according to how the participant acquired that food aversion: "physiological" refers to immediate reactions to the food, such as vomiting or stomach problems; "social learning" refers to an explicit statement that someone told them to avoid that food (i.e., "advice"); "learning" refers to reasons, such as abortion, that could have been due either to a previous personal experience or to information provided by someone else (thus, "learning" potentially includes both individual and social learning). We left

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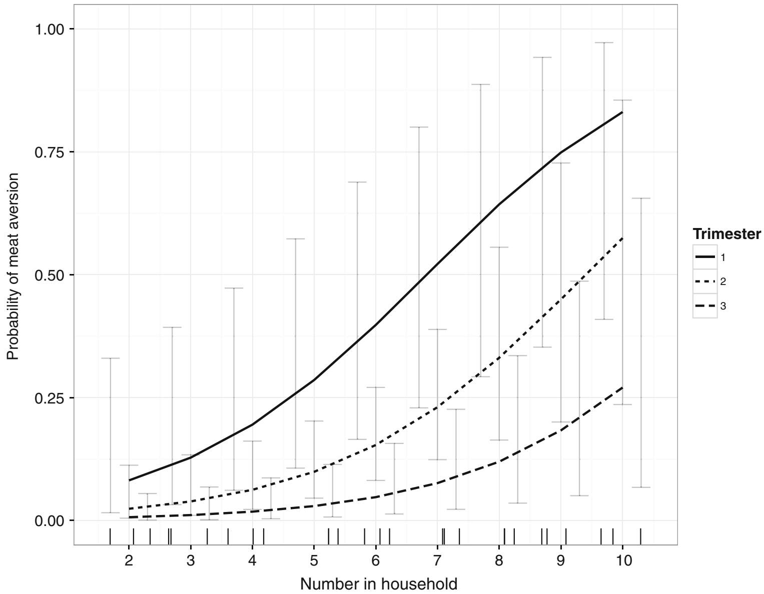

Fig. 3 Exploratory logistic regression model of meat aversions as a function of household size and trimester (Table 5, model 2). *Gray bars* represent 95% confidence intervals. A small amount of jitter was added to improve display of overlapping points

"heat" as is because it is a key concept in humoral theory, and because we were unsure if it involved immediate physiological responses to foods, or individual or social learning (Table 6).

The heatmaps in Fig. 4 display the etic (top) and emic (bottom) food categories cross-tabulated with reasons for avoiding those foods (left) and with how the aversion was acquired (right). Rows and columns of each heatmap were clustered using the Euclidean metric and Ward agglomeration.

Table 5 Reasons for avoiding foods

Reason for aversion	Number of foods	Percent of avoided foods
Heat	36	33.3
Fetal harm	27	25.0
Abortion	13	12.0
Advice	9	8.3
Stomach problem	6	5.6
Unknown	5	4.6
Vomiting	5	4.6
Baby appearance	3	2.8
Bad taste	3	2.8
Cold	1	0.9

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Table 6 How food aversions were acquired

How aversion acquired	Number of foods	Percent of avoided foods
Learning	44	40.4
Heat	36	33.0
Physiological	14	12.8
Social learning	9	8.3
Unknown	6	5.5

The first cluster analysis of etic food categories (Fig. 4, top left) showed that heat, abortion, and fetal harm form one major cluster of reasons to avoid these foods, with all the other reasons grouped in a second cluster. It also showed that fruits form their own

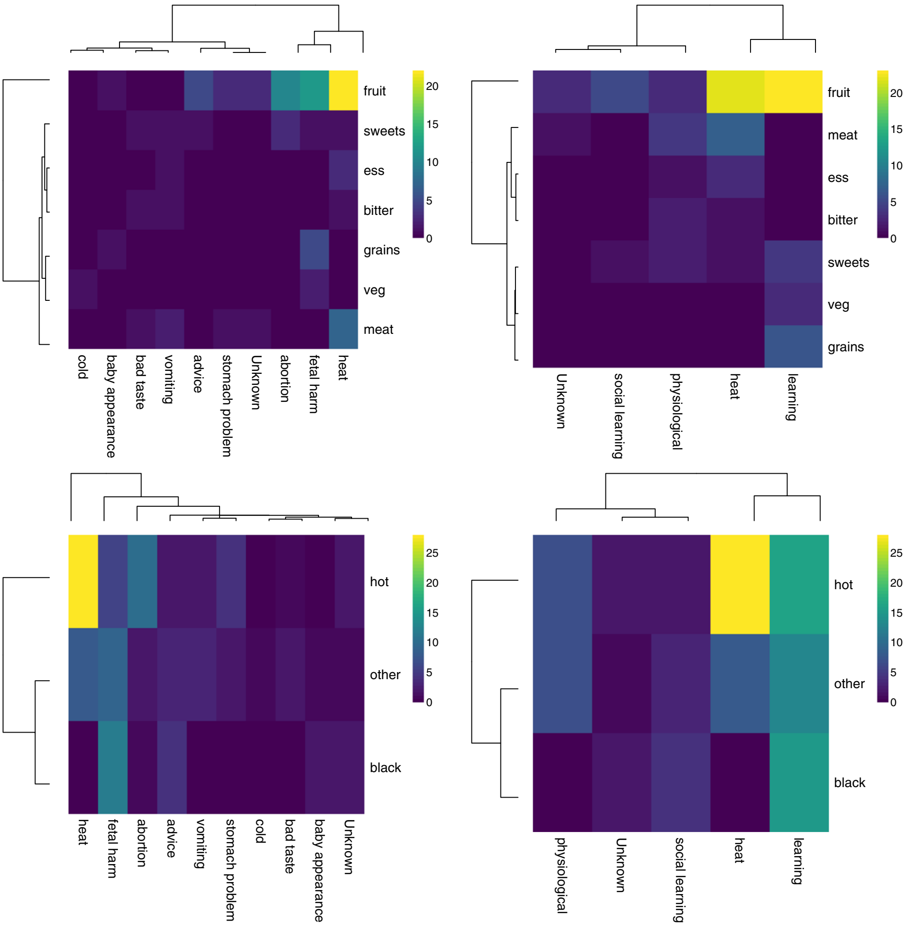

Fig. 4 Heatmaps displaying the etic (*top*) and emic (*bottom*) food categories crosstabulated with reasons for avoiding those foods (*left*) and with how the aversion was acquired (*right*). Colors indicate the number of avoided foods in each cell. Rows and columns clustered using the Euclidean metric and Ward agglomeration method

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cluster and were primarily thought to be dangerous to the pregnancy. The second cluster analysis (Fig. 4, top right) showed that aversions to foods in the etic categories were often acquired by some form of learning, and that "heat" clustered with learning. All other means of acquiring food aversions in the etic categories formed a second cluster.

Emically classified foods were avoided primarily because of "heat," fetal harm, or abortion (Fig. 4, bottom left). Hot foods were primarily avoided because of their "heat," not surprisingly, but learning was also important. Black foods, on the other hand, were avoided largely due to learning. Other foods were avoided primarily due to learning, although "heat" and physiological responses were also important factors (Fig. 4, bottom right).

Discussion

Study 1

Study 1 found that fruits (e.g., naval, papaya, black grapes) were the most commonly avoided foods during pregnancy, not meat or vegetables, which have received the most emphasis in evolutionary models of food aversions during pregnancy. Avoiding "hot" foods such as papaya and mango is common in South India during pregnancy (Nag 1994; Nichter and Nichter 1983). Many participants in Study 1 also reported that consumption of black fruits could lead to abortion or a disease characterized as black or blue patches on the infant's skin (*manthai*; Placek and Hagen 2013). Research conducted in Northern Peru found that black organic matter is considered cooling and healing, rather than harmful (Oths 1992). Aside from this research, little is known about the organeleptic properties of black food and its relationship to dietary preferences in pregnancy.

One possible explanation for avoiding fruits is that many fruits are potential allergens (e.g., papaya and unripe mango), especially to individuals allergic to latex (latex-fruit syndrome; Wagner and Breiteneder 2002). Anaphylaxis during pregnancy can be catastrophic to the mother and/or fetus (Simons and Schatz 2012). Natural latexes appear to serve a defensive role against herbivores (Konno 2011); therefore, avoiding foods containing them is consistent with the evolutionary model of fetal protection from plant teratogens (Hook 1976; Profet 1988).

Study 1 participants also reported that women were most likely to crave sour food items. This is similar to a previous study on pica and amylophagy in which participants reported that unripe mango and unripe tamarind (both sour items) are the most common craving in pregnancy (Placek and Hagen 2013). Certain fruits might have beneficial effects on health. For example, studies have shown that naval fruit (*Syzygium cumini*), an avoided food in the current study, can reduce blood-glucose levels (Kumar et al. 2008). More research is required to resolve the apparent paradox that the most-avoided food category is also the most craved, which might be a consequence of the diversity of fruits in the diet of this population.

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Study 2

Study 2 found modest support for the hypothesis that pregnancy meat aversions are explained, in part, as a mechanism to protect the fetus from toxins and/or pathogens, and that seemingly culturally transmitted food proscriptions play a surprisingly large role in pregnancy diet.

Etic Food Categories

The fetal protection model (pathogen-specific) was the best a priori model of meat aversions. This finding supports the pathogen avoidance hypothesis proposed and empirically supported by several scholars (Fessler 2002; Flaxman and Sherman 2000), with the caveats that only 11.7% of participants reported aversions to meat, and the model AUC value indicated only "fair" support (Table 4, model 1). A simplified exploratory model with trimester of pregnancy and number household family members (Fig. 3) outperformed the a priori pathogen-specific fetal protection model (Table 4, model 2). As in many previous studies, we found heightened aversions in the first trimester, which is consistent with the fetal protection hypothesis (Fessler 2002; Flaxman and Sherman 2000; Profet 1988). We also found that aversions were predicted by increasing family size, controlling for trimester. Because larger family size is a risk factor for infections (Bhat and Manjunath 2013; Kristensen and Olsen 2006), this might also support the pathogen-specific fetal protection model. Larger family size could also influence diet via other pathways; for example, it could indicate greater competition for food (e.g., Hagen et al. 2006). To test this idea, we added income and food insecurity to our exploratory model, but adding these variables did not diminish the effect of family size on meat aversions (results not reported). The effect of family size on meat aversions warrants further investigation.

Despite the support for the pathogen avoidance model in our findings, we note that researchers in reproductive immunology are expressing increasing skepticism that women are "immunosuppressed" early in pregnancy (Kraus et al. 2012; Pazos et al. 2012; Racicot et al. 2014). Perhaps it is not that women are immunosuppressed in the first trimester but rather that infections, if they do occur, are especially costly to the mother and fetus. Alternatively, perhaps pregnant women are more susceptible to a few pathogens, such as *Listeria* (Kourtis et al. 2014). Under all these hypotheses, there would still be selection for pathogen avoidance mechanisms.

We found no compelling evidence that aversions to etic food categories were predicted by the resource scarcity, psychological distress, or demographic models.

Emic Food Categories

The "hot" foods, six of which were fruits and two of which were meats, were avoided by 37.2% of pregnant women in Study 2 and thus were second only to fruits as the most consistently avoided foods. This suggests the important influence of humoral theory on dietary decisions, specifically the belief that consuming hot foods can induce abortion, as reported by participants in Study 1. "Black" foods, which are thought to cause manthai, were also widely avoided (and never craved) (Fig. 2).

Most foods were avoided by Study 2 participants because they were "hot," or caused fetal harm or abortion (Table 5). According to Study 1 participants, "hot" foods should

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be avoided largely because they cause abortion. Our cluster analysis indeed found that "heat," fetal harm, and abortion formed a single cluster of reasons to avoid foods (Fig. 4, top left). It also found that fruits (Fig. 4, top left) and "hot" foods (Fig. 4, bottom left) were mostly avoided for these reasons.

Food aversions were acquired primarily through learning and because of their "heat" (Table 6). Our cluster analysis showed that "heat" and learning formed a cluster (Fig. 4, right), which suggests that the negative consequences of "heat" are learned from others and/or from personal experience, although we cannot rule out that there is a physiological component to "heat." Nevertheless, "heat" is a component of humoral theory, a culturally acquired model of health. Thus, it is likely that social learning plays a central role in these food aversions.

Although 37.2% of women reported aversions to "hot" foods, 62.8% did not. This variation was best predicted by psychological distress, which has been shown to influence diet in pregnancy (e.g., Neufeld 2011), but the model had a relatively low AUC of 0.65 (Table 4, model 3). Women in the current study who had higher psychological distress had higher levels of food insecurity (r_S=0.5, p=2.5 x 10^{-7}), but adding food insecurity to the model did not improve fit by AICc (results not reported). It is possible that women who are psychologically distressed are more likely to adhere to cultural norms in order to avoid criticism, which would exacerbate distress. By and large, our a priori models did not explain much variation in the avoidance of "hot" (Table 4) or "black" foods (Table S6).

Cultural beliefs and attitudes have been relatively neglected in evolutionary research on pregnancy diet choice. Henrich and Henrich (2010) argue that culturally evolved food taboos protect pregnant and lactating women from dietary toxins. Women in Study 1 and Study 2 expressed particular concern about foods they thought to be abortifacients. Miscarriages, which can be caused by environmental toxins (Gardella and Hill 1999), occur in at least 12–15% of clinically recognized pregnancies, which means a large fraction of women will experience a miscarriage in their lifetime. Miscarriage is traumatic for women (Lee and Slade 1996), and this might motivate careful evaluation of dietary choices during pregnancy. Determining which foods in the local environment are teratogenic by individual learning is difficult, however, because physiological cues of toxicity, such as bitterness, do not reliably indicate teratogenicity (Slotkin et al. 2006). Hence, women might have evolved to rely heavily on social learning (culture) for guidance on diet during pregnancy (Boyd and Richerson 2004; Henrich and Henrich 2010). Several participants stated that elders transmitted knowledge of food aversions, implying either vertical (one-to-one) or conformist (many-to-one) transmission (Hewlett and Cavalli-Sforza 1986).

Limitations

This study used a correlational design, which limits our ability to establish causation. Furthermore, although women reported aversions to specific foods, we did not collect detailed information about how often they consume these items. For example, Young and Pike (2012) found that individuals were averse to specific foods but nonetheless consumed them because of the lack of other types of food. Given that a proportion of the population in the current study is food insecure, this data would have shed additional light on dietary preferences in pregnancy. We also do not know if "hot" or

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"black" foods do increase miscarriages or cause other health problems, as many participants believed. Results from the current study, which had a modest sample size, might not generalize to pregnant women in other populations. Finally, this study did not differentiate between avoidances and physical aversions to food. A strength of the study, relative to some others, is that it interviewed women who were currently pregnant, rather than asking them to recall cravings and aversions from an earlier pregnancy.

Conclusion

Our tests of five a priori hypotheses of pregnancy food aversions in a population with high levels of food insecurity and infectious disease found modest support for the hypothesis that putatively innate food aversions function to protect the fetus, especially from pathogens. An exploratory model found that trimester and number of household members were strong predictors of aversions to meat. Although we included household size as an index of pathogen exposure, it may in fact index some other factor important to diet. This study also found surprisingly frequent aversions to fruit, which might be due to the presence of latex and other allergens that pose a risk to the mother and fetus. We found no compelling support that resource scarcity, psychological distress, or demographic models predicted aversions to etic food categories, although psychological distress did predict aversion to "hot" foods.

Our most important finding is that a socially learned model of health, humoral theory, plays an unexpectedly large role in pregnant women's food aversions. Whereas 11.7% of women avoided meat and 3.19% avoided vegetables, 37.2% avoided at least one "hot" food and 18.1 avoided at least one "black" food (most of which were fruits, which were avoided by 39.4%). Unlike meat, which was avoided primarily in the first trimester, fruits were avoided throughout pregnancy. Future research on dietary shifts in pregnancy should include socioecological factors such as household size, fruits and other allergenic foods, and culturally acquired models of diets that are healthy and harmful to the fetus and mother.

Acknowledgments The authors would like to extend special thanks to study participants as well as to Krishnaswamy Gayatri, Vibha Gopal, and Xavier and Hushmija Mariadoss for their hospitality and assistance during the data collection process. We also give our sincere gratitude to the National Folklore Support Centre in Chennai, Tamil Nadu. Special thanks are owed the WSUV Bioanthropology lab group and Marsha Quinlan. Finally, we thank three anonymous reviewers for their exceptionally helpful comments and suggestions. Funding was provided by Washington State University's Graduate and Professional Student Association (GPSA).

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