ASSOCIATION OF ENVIRONMENTAL FACTORS AND ADIPOSITY IN THAI SCHOOL CHILDREN: A STRUCTURAL EQUATION MODELING APPROACH

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Abstract. This study used structural equation modeling (SEM) to examine associations between environmental factors and indicators of adiposity. We analyzed data from a cross-sectional Southeast Asian Nutritional Survey of 1,161 Thai children aged 7.0-12.9 years who were recruited by multi-stage sampling. Standardized questionnaires provided data on socio-economic, health status, and physical activity, while a 24-hour dietary recall provided dietary intake data. SEM analysis show that socio-economic, health status, physical activity, and nutrient intake were not associated directly with adiposity, but their relationship with adiposity was via the environment. This analysis confirms many relationships between possible causal factors and adiposity, and it enables insight into the complex mechanisms leading to higher body fat. As such, it could serve as a working model to combat the increasing prevalence of obesity (excess body fat) affecting many countries.

Keywords: adiposity, environment, obesity, Southeast Asian Nutritional Survey, structural equation modeling, Thai children

INTRODUCTION

Adiposity is the quality or state of being obese. Obesity is a worldwide public health epidemic affecting both developed and developing countries (Kelishadi, 2007; Bhurosy and Jeewon, 2014; Ng *et al*, 2014). Although still relatively low in Thailand (Aekplakorn and Mo-Suwan, 2009), compared to Western countries, prevalence of overweight and obesity in Thai children and adults is rising (Janssen *et al*, 2005; Sirikulchayanonta *et al*, 2011; Ng *et al*, 2014). A recent study (Rojroongwasinkul *et al*, 2013) in a nationally representative sample found an overall prevalence of 9.6% overweight and 10.6% obesity among Thai children, with higher values in urban areas compared to rural areas. This same study also showed persistently high prevalence of stunting and underweight. Thailand is not the only Asian country experiencing this double-burden of over-nutrition and under-nutrition (Florentino, 2002). Population studies

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conducted at the same time in Malaysia (Sandjaja *et al*, 2013), Indonesia (Poh *et al*, 2013) and Vietnam (Le Nguyen *et al*, 2013) showed a similar pattern, although the ratios between under- and over-nutrition differ across the four countries (Schaafsma *et al*, 2013).

Factors affecting prevalence of overweight and obesity are well known (Bhurosy and Jeewon, 2014) and include excess nutrient intake, food choices [fat and refined carbohydrate (sugar)-rich foods], food habits, environmental factors (educational level of parents and income), and physical activity (Jitnarin *et al*, 2010). The relative contribution of these causal factors can vary between countries and between societies and can also vary over time. For this reason, regular nutritional status monitoring, which also examines the effects of associated factors is important, as it facilitates a targeted approach for combating overweight and obesity.

Past research studies have examined the relationship among factors affecting adiposity by using multiple linear regression and/or correlation analyses (Yamborisut *et al*, 2009; Wilkie *et al*, 2016). An alternative approach is structural equation modeling (SEM), which is a statistical technique for testing several causal paths simultaneously as well as utilizing multiple variables. This approach improves the understanding of mechanisms of the relationships among various factors (Nelson *et al*, 2008; VanderWeele, 2012). Consequently, the present study used SEM to examine associations between environmental factors (*ie*, socio-economic status, health status, physical activity, nutrient intake) and indicators of adiposity [body mass index (BMI), sum of four skinfolds, waist circumference] as latent response variables.

MATERIALS AND METHODS

Data source

The study used data from the Southeast Asian Nutritional Survey (SEANUTS) in Thailand (Rojroongwasinkul *et al*, 2013; Schaafsma *et al*, 2013). SEANUTS is a cross sectional survey that collected information on socio-economic status, health status, physical activity, nutrient intake, and nutritional status for children aged 0.5-12 years in 4 Southeast Asian countries (Indonesia, Malaysia, Thailand, and Vietnam) (Schaafsma *et al*, 2013). In Thailand, 3,119 children participated in the survey (Rojroongwasinkul *et al*, 2013). A multistage cluster sampling method was used to select participants from 4 regions of Thailand, *ie*, central, north, northeast and south (76 provinces), including Bangkok.

In the first stage of sample selection, random sampling was done to select the representative province for each region, one province from the central, north and south regions and two provinces from the northeast region as it is the largest region of the country. Bangkok, the capital city, was chosen as one study site due to its difference in characteristics compared with the other chosen provinces, which might influence lifestyle and also was considered as urban. In the second stage, each province (except Bangkok) was divided into urban (municipal) and rural (nonmunicipal) areas, and then villages in each area were selected randomly. Within each village, a random sample of household was selected, and only one child per household was recruited. Information on the subject was obtained by interviewing the child and parents or legal guardians. The study was registered in the Netherlands Trial Registry (NTR2462) and was conducted according to guidelines laid down in the Declaration of Helsinki

(2008). All procedures of this study were approved by the Committee on Human Rights Related to Research Involving Human Subjects of the Faculty of Medicine Ramathibodi Hospital, Mahidol University (MURA 2010/467), Thailand. Prior written informed consent was obtained from the parents or legal guardians of each participant. For the current study, data of children aged 7.0 to 12.9 years were used (N = 1,161).

Variables

The analysis presented here focuses especially on latent variables. A latent variable is a variable that cannot actually be measured as it is derived from a number of variables. Socio-economic status is a good example, because it is difficult to define as it contains variables concerning income, educational level of parents and living environment. In this study, a latent variable is marked by an apostrophe.

Environment as a latent variable is defined as family and individual level variable, including socioeconomics, health status, physical activity and nutrient intake that influence individual decision, action, and overall nutrition and health outcomes. Thus, environment is conceived as both external and individual contexts in which individual decisions are made and actions taken. Data on socio-demographic variables were obtained from parents or legal guardians using standardized questionnaires. For household income, maternal and paternal education, and residential area (urban/rural), a latent variable 'socioeconomic' is derived.

The study questionnaires also sought information regarding subjective general health status of the child (poor, fair and good), health problem (presence of chronic diseases, *ie*, asthma, epilepsy, diabetes and heart disease) and regular use of medication (yes or no), these three indicators bring categorized as latent variable 'health status'.

A questionnaire on physical activity collected information regarding participation in sports or physically active behavior during school recess time (counted in number of times per day), time spent (hours per day) in watching television or using a computer (screen time), and hours of sleep per day (sleep time). This information formed the basis for the latent variable 'physical activity'.

Food intake data were collected using a 24-hour recall questionnaire. The reported food items were converted into nutrient intakes using the INMUCAL-N V.2.0 computer software (Institute of Nutrition, Mahidol University), which calculates nutrients based on a Thai food composition database. Macro nutrients, energy, protein, and fat were used as basis for the latent variable 'nutrient intake'.

Adiposity as a latent variable is derived from BMI, sum of four skinfolds and waist circumference. Weight in light indoor clothing was measured to the nearest 0.1 kg using a calibrated digital scale (Seca model 882, Humburg, Germany). Height was recorded barefoot with a wall mounted microtoise (Stanley-Mabo, Besançon, France) to the nearest 0.1 cm. BMI was calculated as weight/height squared (kg/m^2). Overweight and obesity were defined based on WHO growth reference (2007) using BMI for Age Z-scores (BAZ). Overweight is BAZ >1 SD to ≤2 SD and obesity BAZ >2 SD (de Onis *et al*, 2007).

Skinfold thickness was measured at four sites (tricipitalis, bicipitalis, subscapularis and supra-iliacalis) to the nearest 0.2 mm using a skinfold caliper (Holtain, Crymych, UK). The sum of four skinfolds was used in the analysis (Kettaneh *et al*, 2005).

Waist circumference was measured midway between lower rib margin and iliac crest using a Seca 201 flexible measuring tape (Seca Corp, Chino, CA) to the nearest 0.1 cm.

Statistical and SEM analysis

Summary statistics and frequency distribution were calculated for demographic and observed variables.

SEM was used to develop an association model between environmental factors and adiposity indicators based on previous studies (Hendrie *et al*, 2012; VanderWeele, 2012). SEM is a statistical technique that can be used to test a theoretical framework with linear related observed (manifest) or unobserved (latent) variables. As noted above, latent data are variables that cannot be directly measured (unobserved variables) but are derived from a number of measured data. SEM begins by assessing whether a sample covariance or correlation matrix is consistent with a hypothetical matrix implied by the model. The inputs are either observed data or latent variables computed from the data in the model to be evaluated.

SEM is a combination of factor analysis and multiple regression and consists of a series of multiple regression equations. The response variable in one regression equation in an SEM may appear as a predictor in another equation, *ie*, these variables may influence one another reciprocally, either directly or through other variables as intermediaries (indirect). All these equations are meant to represent causal relationships among the variables in the model (Chan, 2015).

SEM modeling procedure has two distinct parts: measurement and structural. The measurement part defines relationships between observed and unobserved (latent) variables. The structural part defines relationships among the unobserved variables by specifying the pattern by which particular latent variables directly or indirectly influence some other latent variables in the model.

In this study, goodness of fit of the SEM model was evaluated by chi-square test, root mean square error of approximation (RMSEA), and comparative fit index (CFI) (Byrne, 2001). A valid model has χ^2/df values ranging from 2 to 5. RMSEA estimates the lack of fit in the current mode compared to a saturated model (good model) and should have values < 0.05. CFI investigates the fit of the current model relative to the independence model. CFI values > 0.90 indicate reasonably good fit of a model (Hu and Bentler, 1999). R^2 (coefficient of determination) indicates how much of the variability in the response variable is explained by explanatory variables (Byrne, 2001). SEM analysis was conducted using IBM SPSS Amos 20 software. SPSS version 20.0 (IBM, Armonk, NY) was used for other statistical analysis.

RESULTS

Data regarding the overall physical characteristics, nutrient intake, and physical activity characteristics of the children were collected (Table 1). There were approximately equal number of boys and girls, among whom 23.5% were overweight or obese. BMI, sum of skinfolds and waist circumferences were highly correlated with correlation coefficients of 0.8. The children spent an average 1.9 hours per day (ranging from 8.5 minutes > 8.7 hours) watching television or playing computer game. The average sleeping time was 9.8 hours (ranging from 5.3 to 13.0 hours).

Table 1
Physical characteristics, nutrient intake, and physical activity characteristics in Thai school children (N = 1,161).

	%	Mean	SD
Boys	49.8		
Overweight + Obesity	23.5		
Age (years)		9.9	1.7
Body mass index (kg/m^2)		17.3	4.0
Sum of four skinfolds (mm)		40.9	24.3
Waist circumference (cm)		58.6	10.6
Energy intake (kcal)		1,385	267
Protein intake (g)		52	15
Fat intake (g)		44	15
Active periods during school recess time		1.4	0.9
Screen time (hours/day)		1.9	1.3
Sleeping time (hours/day)		9.8	1.0

Overweight, WHO BMI for age z-score > 1 SD to ≤2 SD and Obesity, WHO BMI for age z-score > 2 SD. Sum of four skinfolds, sum of tricipitalis, bicipitalis, sub-scapularis and supra-iliacalis; active periods during school recess time, number of active play during school recess times; screen time, times behind TV, computer, or video game.

Thirty-one point three percent of the children were from urban areas (Table 2). The average household income of the parents was 10,000 Baht (USD 304) per month.

Tested SEM model for causal factors of adiposity showed a χ^2/df of 1.79, a CFI value of 0.968 and RMSEA of 0.026 (Fig 1). All three values imply that the proposed model agrees well with the data. 'Nutrient intake' is directly related to 'environment' (β = 0.27) and the standardized regression coefficient is high for 'physical activity' (β = -0.48), low for 'socioeconomic' (β = 0.12) and not significant for 'health status' (β = -0.11). The direct effect that 'environment' had on 'adiposity' is significant (β = 0.51). BMI, sum of four skinfolds and waist circumference have low correlation with 'adiposity' (R^2 = 0.28), but the correlation with 'environment' is high (R^2 = 0.93).

The direct effect, *ie*, effect of an independent variable on a dependent variable) of physical activity (independent variable) on environment (dependent variable) was -0.48 (Table 3). The indirect effect, *ie*, the effect of an independent variable on a dependent variable, of physical activity on adiposity, on body mass index, on waist circumference, and on sum of four skinfolds was -0.25, -0.26, -0.24, and -0.25, respectively. Adiposity also had the highest total effect (sum of direct and indirect effects) and direct effect on BMI, waist circumference and sum of four skinfolds, namely, 1.02, 0.96 and 0.98, respectively.

DISCUSSION

The present study was conducted in a representative sample of Thai children as part of the Thai SEANUTS study (Rojroongwasinkul *et al*, 2013). Emphasis during data collection was on standardization of measurements and of information col-

Table 2
Socio-demographic characteristics, family income, and subjective health status in Thai school children.

	n (%)
Area	
Rural	797 (68.6)
Urban	364 (31.4)
Father's education	
Primary school or lower[a]	640 (55.1)
Secondary school and higher	521 (44.9)
Mother's education	
Primary school or lower[a]	601 (51.8)
Secondary school and higher	560 (48.2)
Household income (Baht[b]/month)	
Median	10,000
(25th, 75th percentile)	(5,200, 17,000)
General health status	
Good[a]	914 (78.7)
Fair + Poor	247 (21.3)
Need medication	
No[a]	1,107 (95.3)
Yes	54 (4.7)
Having health problems	
No[a]	997 (85.9)
Yes	164 (14.1)

[a]Reference group; [b]USD 1= THB 32.9.

lection via questionnaire. The response rate was high. The SEANUTS study showed that in Thailand children are affected by over-nutrition or malnutrition (Le Nguyen *et al*, 2013; Poh *et al*, 2013; Rojroongwasinkul *et al*, 2013; Sandjaja *et al*, 2013). Moreover, data from recent studies in Thailand showed that childhood overweight and obesity are increasing (Mo-suwan *et al*, 2000; Sakamoto *et al*, 2001; Aekplakorn and Mo-Suwan, 2009). Thus, knowledge of the factors related to overweight and obesity is important for monitoring and, ideally, reversing this pattern.

SEM was chosen as the main technique with a focus on latent variables, rather than regression analyses or GLM techniques (Byrne, 2001; Nelson *et al*, 2008). The study shows that the latent variables, namely, 'socioeconomic', 'health status' and 'physical activity' were inversely related to 'environment', indicating that higher socioeconomic status, better health status and more active life style negated against environmental factors that lead to adiposity. Moreover, the observed effect of physical activity in this study is consistent with previous research (Gordon-Larsen *et al*, 2000). The effect of socio-economic status on obesity is well known and has been reported in many recent studies including those focusing on children (Aekplakorn and Mo-Suwan, 2009; Dinsa *et al*, 2012). The

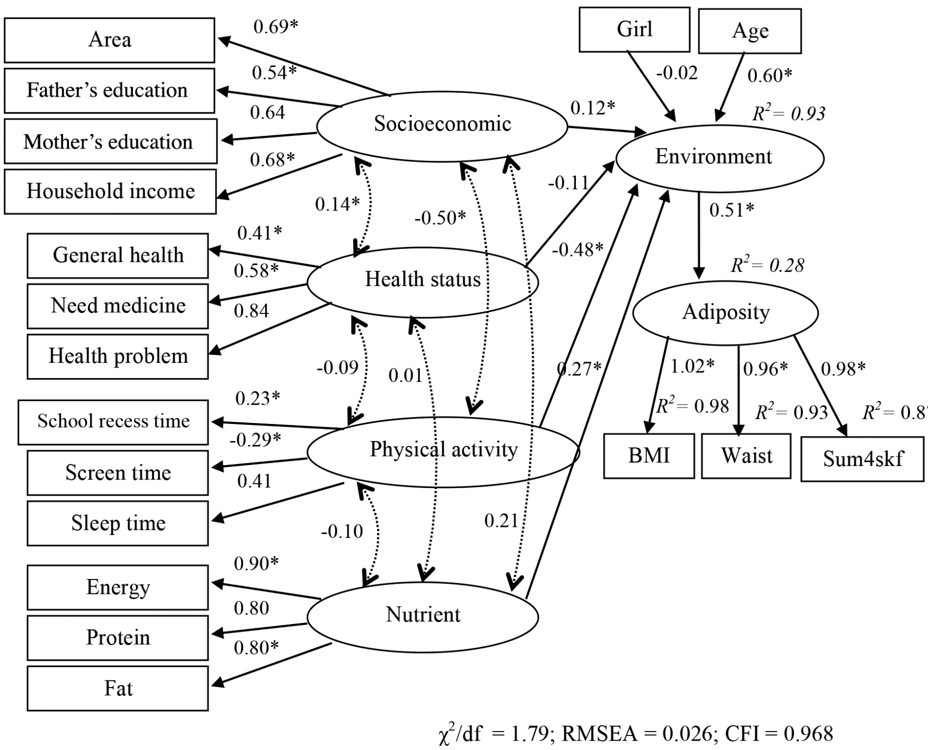

Fig 1–Structural equation model of observed and unobserved variables affecting adiposity variable (derived from BMI, waist and sum of four skinfolds). $^*p < 0.01$.

effect of 'health status' was small and not significant in this study sample. However, in adults such an effect has been reported (Inge *et al*, 2013). One possible reason why this was not found in our children population might be due to their young age (7.0 to 12.9 years old). It takes time for a non-optimal health status to lead to adiposity (Rolland-Cachera *et al*, 2006; Wells and Fewtrell, 2006).

'Nutrient intake' had a (small) positive effect on 'environment', an obvious finding (Elliott *et al*, 2011), although usually it has not been found in studies related to the association between energy intake and adiposity (Rocandio *et al*, 2001; Elliott *et al*, 2011). This is due mostly to shortcomings in study design and/or methodology used (Carlson and Morrison, 2009).

Gender played a very small role and has no significance on 'environment'. Although this seems to be contradictory, it can be explained by the fact that gender is related to other factors, such as 'nutrient intake' and 'physical activity'.

In conclusion, SEM analysis shows that 'socioeconomic', 'health status', 'physical activity' and 'nutrient intake' were not directly associated with adiposity, but their relationship with adiposity was via 'environment'. In addition, the SEM model confirmed many relationships between possible causal factors and adiposity previously reported. Furthermore,

Table 3
Standardized direct, indirect, and total effects of the structural equation models using environment and adiposity as latent response variables.

Effect	Direct	Indirect	Total
Environment ← Nutrient_intake	0.27		0.27
Environment ← Socioeconomic	0.12		0.12
Environment ← Physical_activity	-0.48		-0.48
Environment ← Health_status	-0.11		-0.11
Environment ← Age	0.60		0.60
Environment ← Girl	-0.02		-0.02
Adiposity ← Nutrient_intake		0.14	0.14
Adiposity ← Socioeconomic		0.06	0.06
Adiposity ← Physical_activity		-0.25	-0.25
Adiposity ← Health_status		-0.06	-0.06
Adiposity ← Age		0.31	0.31
Adiposity ← Girl		-0.01	-0.01
BMI ← Nutrient_intake		0.15	0.15
BMI ← Socioeconomic		0.06	0.06
BMI ← Physical_activity		-0.26	-0.26
BMI ← Health_status		-0.06	-0.06
BMI ← Age		0.32	0.32
BMI ← Girl		-0.01	-0.01
BMI ← Adiposity	1.02		1.02
Waist ← Nutrient_intake		0.14	0.14
Waist ← Socioeconomic		0.06	0.06
Waist ← Physical_activity		-0.24	-0.24
Waist ← Health_status		-0.05	-0.05
Waist ← Age		0.30	0.30
Waist ← Girl		-0.01	-0.01
Waist ← Adiposity	0.96		0.96
Skf4sum ← Nutrient_intake		0.14	0.14
Skf4sum ← Socioeconomic		0.06	0.06
Skf4sum ← Physical_activity		-0.25	-0.25
Skf4sum ← Health_status		-0.05	-0.05
Skf4sum ← Age		0.31	0.31
Skf4sum ← Girl		-0.01	-0.01
Skf4sum ← Adiposity	0.98		0.98

SEM enabled insights into the complex and sometimes confusing mechanisms that lead to adiposity. As such, it could serve as a working model to combat the increasing prevalence of obesity or excess body fat that is affecting Thailand and other countries as well.

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CONFLICT OF INTERESTS

None of the authors or the research institutes has any conflict of interests. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of FrieslandCampina.

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