China's Nutrition Transition: The Effects of Rapid Social Change on Adult Activity Patterns and Overweight

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ABSTRACT

Keri L. Monda: China's Nutrition Transition: The Effects of Rapid Social Change on Adult Activity Patterns and Overweight
(Under the direction of Barry M. Popkin, PhD)

The rising prevalence of overweight throughout the world has prompted the recognition of a "global epidemic," with increases being partially attributed to population-level reductions in physical activity and increases in sedentary behaviors. In China, overweight has started to emerge as a significant public health concern. Prospective research on the relationship between physical activity and overweight is relatively uncommon in the developing world, and China offers a unique opportunity for study given the tremendous increases in urbanization and economic development seen in the recent past. Such growth can impact the physical activity patterns of individuals by driving concomitant increases in car ownership, in labor-saving household devices, in the mechanization of the workplace, as well as decreases in the proportion of the workforce employed in more physically-demanding occupations. The purpose of this research was to examine the impact of urbanization on the physical activity patterns of Chinese adults, as well as to investigate the impact of these changes on weight status. Analyses were conducted using data from the China Health and Nutrition Survey, an ongoing longitudinal study of a socioeconomically and demographically diverse sample of the Chinese population. Using multilevel models we showed that community-level urbanization was importantly associated with occupational activity after adjustment for individual-level sociodemographic factors. In subsequent analyses we found both occupational and household activity to be important predictors of weight in men and women, while leisure time and transportation activity did not have the same effect. This research helps to fill an important gap in understanding the impact of urbanization on physical activity and on subsequent overweight in an enormous transitioning populace.

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I. Introduction

A. Background

China is one of the world's most rapidly growing economies, and increased industrialization, urbanization, globalization, and economic development have led to substantive changes in the Chinese lifestyle and increased access to technology in the home and work environments. In the wake of lifestyle changes, there have been substantial increases in the prevalence of overweight and obesity such that they have now emerged as major public health concerns. Increases in overweight have been partially attributed to decreases in physical activity and increases in sedentary behavior, and urban residence itself has been shown to be an important predictor of overweight in developing countries. One potential mechanism through which this may be operating is that increased access to labor-saving technologies in the home and work environments has led to decreases in overall energy expenditure. If so, we may expect to see even further increases in overweight as China's nutrition transition continues.

Physical activity is a complex behavior and takes place in multiple domains, including occupational, domestic, active transportation, and in leisure time. However, few studies have simultaneously examined multiple domains of physical activity to evaluate the effect of each on body weight. In China, leisure time sports and exercise is still relatively uncommon and adults gain the majority of their overall physical activity in their work and domestic lives. Thus, excluding these lesser-examined types of physical activity could lead to an underestimation of overall physical activity and failure to find an effect of activity on weight status where one may be operating. Further, while in general there is a dearth of longitudinal population-level studies examining the effect of activity on weight status, this lack is even more severe in developing countries.

In this work we sought to improve the understanding of the ways in which an individual's environmental context plays a role in his or her occupational physical activity, over and above well-studied individual-level predictors. Further, using detailed interview data encompassing type, intensity, frequency, and duration of activity, we quantified energy expenditure from multiple domains (including occupational, domestic, transportation, and leisure time) to investigate their separate effects on weight status.

In this study we used data from the China Health and Nutrition Survey (CHNS), a socioeconomically and demographichally diverse longitudinal sample with hierarchical (e.g. individual-, household-, and community-level) data collected in 1989, 1991, 1993, 1997, and 2000. These data from a highly dynamic society undergoing rapid change provide us with a unique opportunity to study the important health effects stemming from economic development and to more fully understand the important determinants of overall physical activity, but also to clarify the relationship of changes in multiple domains of physical activity to weight status.

B. Research Aims

The overall goal of this research was to improve our understanding of the effect that urbanization has had on physical activity patterns of Chinese adults in a rapidly-transitioning society, and the subsequent effect of these changing activity patterns on weight status. Specific aims of this work were as follows:

1. Physical activity associated with occupational work is an important source of energy expenditure in developing economies and is expected to decline in response to increasing urbanization and modernization. For this aim, we hypothesized that the occupational physical activity of individuals is affected by the level of urbanization in their communities, over and above individual-level predictors. Data from the 1991, 1993, and 1997 survey years was utilized due to availability of the urbanicity measure. We used a three-level logistic random intercept multilevel model to quantify the effect of urbanization on occupational physical activity and to account for the nesting of measurement occasions (level 1) within individuals (level 2) and communities (level 3). This type of model provided us with a framework with which we could assess the effects of covariates measured at different levels of the hierarchy on the outcome.

2. Physical activity analyses in adults often ignore work-related sources of activity in favor of leisure-time activity. Similarly, research on domestic work is very limited worldwide. For this aim, we hypothesized that both occupational and domestic energy expenditure would be shown to be important predictors of weight in adult men and women. We used linear random effects models to study the longitudinal relationship of occupational and domestic activity to weight using four waves of survey data (1991, 1993, 1997, and 2000). Using the same type of model, we expanded our analyses to include dimensions of urbanization by examining the effect that owning various labor-saving household devices had on weight, hypothesizing that we would see a direct effect of ownership on

weight. We used random effects models to adjust for the correlation between repeated observations taken in the same subject and to take advantage of their ability to handle longitudinal data on subjects with varying number and unequally spaced observations.

3. Building primarily on aim 2, we sought to increase the scope of our earlier work by including energy expenditure from transportation and leisure time sources along with that from occupational and domestic sources using the last two waves of survey data (1997 and 2000). We also created a measure of total activity by summing energy expenditure from all the different domains. Our aim was to investigate the cross-sectional and longitudinal associations of total and domains of physical activity to weight status. We hypothesized that in cross-sectional analyses higher levels of physical activity, regardless of domain, would be associated with decreased likelihood of being overweight; further, that changes in physical activity would partially explain weight changes over the three-year period. We used multiple longitudinal modeling strategies (linear first-difference, logistic, and multinomial logistic) depending on the specification of the weight status outcome variable.

II. Literature Review

A. The extent of the problem of obesity

Globally there are estimated to be over 1 billion overweight adults, with 300 million obese (WHO 1998; WHO/FAO 2003). This number continues to grow and there are few places in the world where obesity is not rapidly becoming a serious public health issue (Popkin and Doak 1998; Popkin and Gordon-Larsen 2004; Mendez, Monteiro et al. 2005). Obesity arises from an imbalance of the amount of energy consumed and the amount expended, and is dependent upon both environmental and genetic components (Hill and Peters 1998; Kopelman 2000; Speakman 2004). Nonetheless, the epidemic of obesity that we currently face is predominantly environmentally based due to the slow rate of genetic mutation compared to the short period over which we have seen the epidemic emerge. Associations with obesity have been made to increasingly sedentary occupations and lifestyles, increased food intake and portion sizes, and increased dependence on motorized transport (Hill and Melanson 1999; Jeffery and Utter 2003). Increased morbidity and mortality from noncommunicable diseases such as type 2 diabetes, cardiovascular disease, and some cancers are important sequelae of obesity and abdominal fatness, but further associations have been made to reduced physical functioning and quality of life (Must, Spadano et al. 1999; Kopelman 2000; Rainwater, Mitchell et al. 2000; Kumanyika, Jeffery et al. 2002; Patterson, Frank et al. 2004; Kruger, Bowles et al. 2006). Though the extent of obesity in the developing world has yet to reach the proportions seen in the much of the developed world, high rates of urbanization and major shifts in diet and activity place their populations at increasing risk of reaching these levels (Drewnowski and Popkin 1997; Caballero 2001). In fact, a recent paper found that in most developing countries, overweight prevalence exceeds underweight prevalence, especially in urban areas (Mendez, Monteiro et al. 2005). While energy intake and energy expenditure are both essential components of energy balance, this work focuses explicitly on the energy expenditure side. We approached our investigations of physical activity from multiple domains (e.g. leisure time physical activity and occupational physical activity) as well as from multiple levels (e.g. individual and community factors) in attempts to characterize it comprehensively. Further, used longitudinal data to address change over time, an important area of study especially in transitioning countries where the rate of change is rapid and changes may occur in short periods of time.

B. Physical activity has an important relationship with many aspects of health

1. Relationship to overweight and obesity

Numerous cross-sectional studies, mostly done in the U.S., have consistently shown an inverse association between leisure time physical activity (e.g. sports and./or exercise) and obesity (Ching, Willett et al. 1996; Sherwood, Jeffery et al. 2000; Ball, Owen et al. 2001; King, Fitzhugh et al. 2001; Sobngwi, Mbanya et al. 2002). However, due to their cross-sectional nature it is impossible to assess the directionality of the relationship or to differentiate between whether those who are physically active less likely to be obese, or whether those who are not obese more likely to be physically active. In all likelihood, both of these relationships hold. For example, in one study, researchers failed to find an inverse association between moderate or high levels of activity and obesity, but did find that obesity may lead to physical inactivity (Petersen, Schnohr et al. 2004); another found that obese men and women had lower energy expenditure than those who were normal weight (Chen and Mao 2006). Longitudinal or cohort studies are more able to examine the directionality of the association because the exposure, in this case physical activity, is measured earlier in time than the outcome, obesity. Thus, in order to more fully understand the nature of the relationship it is necessary to use prospective data and address questions of incidence of obesity, an area of research that is lacking. Indeed, Trost *et al*. note that, despite recommendations, few new studies have utilized longitudinal data resulting in a continued predominance of results based on cross-sectional data (Trost, Owen et al. 2002).

Findings from the prospective literature of the relationship between leisure time physical activity and obesity are less consistent than those from cross-sectional studies; results differ depending not only on study design and model specification, but on sociodemographic data as well (CDC 1996; Fogelholm and Kukkonen-Harjula 2000; Erlichman, Kerbey et al. 2002; Jakicic 2002; Levine, Peters et al. 2002; Saris, Blair et al. 2003). Nonetheless, many prospective studies do find an inverse relationship between activity and weight, although they tend to suggest a stronger relationship of physical activity to attenuated weight gain and preventing significant weight gain, rather than to preventing overall or reversing age-related weight gain at the population level (Coakley, Rimm et al. 1998; DiPietro 1999). Further, results using measurement of activity at follow-up or at both baseline and follow-up, although modest, were more consistently associated with weight than those using measurements of activity at baseline (Fogelholm and Kukkonen-Harjula 2000).

For illustration, we mention a few cases below. In one longitudinal study of over 15,000 middle-aged adults, the authors found that those who increased the duration or frequency of high-, moderate-, or low-intensity recreational physical activity over 10 years gained less weight, with stronger results in women and in obese individuals (Littman, Kristal et al. 2005). Another study using a cohort of middle-aged women found a similar result and the authors conclude that maintaining or increasing participation in sports or exercise can help prevent or attenuate weight gain (Sternfeld, Wang et al. 2004). Data using a cohort of young black and white adults (CARDIA) which investigated changes in moderate or vigorous participation in sports or exercise on changes in weight found an inverse association between activity and body weight (mean weight gain attenuation of about 1 kg per year), again with substantially larger effects seen in heavier individuals (Schmitz, Jacobs et al. 2000). Using data from a worksite intervention study, French *et al.* found that increased recreational walking or high intensity leisure time activity predicted decreases in the body weight of women, but not in men, indicating that increases in physical activity may be related to weight loss, not just attenuation of weight gain (French, Jeffery et al. 1994). A recent review states that there have been numerous intervention studies exploring the impact of physical activity (exercise) on reducing weight and body fat and that we can conclude from these studies that (1) physical activity promotes fat loss while preserving lean tissue, (2) the rate of weight loss is proportional to the frequency and intensity of exercise, and (3) the addition of physical activity may be an effective strategy for long-term weight regulation (DiPietro 1999).

In sum, the literature examining the relationship of physical activity and obesity is mostly consistent in showing an inverse association in cross-sectional studies; results from prospective studies are mixed, but favor an inverse association as well. Of concern is the noted observation in one review that there may be a manifestation of publication bias in this literature due to the predominance of recent studies in the expected direction (more so than in earlier reviews), although the authors state that this could also be the result of increased sample sizes (Wareham, van Sluijs et al. 2005). Regardless, it is important to keep in mind that the vast majority of investigations have been done in populations from developed countries using leisure time physical activity data to the exclusion of other types. In the research herein we took advantage of a large and diverse population-based longitudinal survey of Chinese adults in whom there have been substantial increases in overweight in the past decade. These data contained detailed physical activity measures from multiple domains; this allowed us to more fully investigate overall activity patterns, their associations with overweight and obesity, and add to scientific knowledge concerning this important relationship.

2. Types of physical activity

As noted above, the majority of physical activity research fails to examine multiple types (domains) of activity (e.g. leisure time, occupational, transportation, domestic) simultaneously. In fact, the predominant type of physical activity investigated is leisure time activity (Fogelholm and Kukkonen-Harjula 2000; Wareham, van Sluijs et al. 2005). Although single-source investigations are informative, they fail to fully characterize overall physical activity or investigate how different sources co-vary or influence one another. Further, total energy expenditure based on a summary from multiple domains may be the more relevant exposure given that the etiological effects of activity are more likely to be related to the totality of activity rather than one domain-specific component. The importance of examining multiple domains of physical activity simultaneously has been made clear in numerous studies which demonstrate that focusing on only one type of physical activity may not only underestimate overall activity (King, Fitzhugh et al. 2001; Craig, Brownson et al. 2002; Tammelin, Nayha et al. 2002), but also misclassify individuals as less active than they really are (Vaz and Bharathi 2004). A number of studies have concluded that the contributions of domestic and work-related physical activity are relevant to determining physical activity-weight associations (Salmon, Owen et al. 2000; Lawlor, Taylor et al. 2002; Evenson, Rosamond et al. 2003; Phongsavan, Merom et al. 2004).

Of the studies that do assess multiple sources of physical activity, they are predominantly U.S. based and focus for the most part on leisure time and occupational sources of activity. For example, King *et al.* in a study to assess the interaction between leisure time physical activity and occupational activity on the prevalence of obesity found that the likelihood of obesity is reduced for both leisure time and occupational activity participation (King, Fitzhugh et al. 2001). In a cross-sectional study of over 12,000 Spanish adults, Gutiérrez-Fisac *et al.* found that neither BMI nor percentage of obesity varied significantly by occupational activity, but that mean BMI were significantly higher in those inactive during their leisure time as compared to those who were vigorously active (Gutierrez-Fisac, Guallar-Castillon et al. 2002). In a prospective study investigating CHD and all-cause mortality, researchers found that physical activity from work and leisure time favorably influenced mortality risks in non-obese men and younger women (Dorn, Cerny et al. 1999).

An important aspect of physical activity studies is also the examination of inactivity. Sedentary behavior during leisure time (typically represented by TV viewing) has been positively associated with obesity in both children (Gortmaker, Must et al. 1996; Andersen, Crespo et al. 1998) and adults (Salmon, Bauman et al. 2000; Hu, Li et al. 2003). While this study does not address leisure time sedentary behaviors, we do examine inactivity as demonstrated by lack of strenuous physical activity during occupational work. This is an important component of our analyses because as China has urbanized, there have been significant shifts in the occupational landscape and many jobs have transitioned from more physically strenuous to more sedentary (Friedman 2005). While few studies have examined inactivity at work, two studies of occupational sitting time in Australian adults found that those who reported high daily levels of sitting were significantly more likely to be overweight or obese than those reporting low daily levels (Brown, Miller et al. 2003; Mummery, Schofield et al. 2005).

Studying multiple types of physical activity may have important implications in terms of the effect seen and total energy expenditure. For instance, Evenson *et al.* conducted a cross-sectional study of African American and white middle-aged adults' leisure time and occupational physical activity and discovered that those with the highest occupational activity had lower participation in sport or exercise across race-gender groups. They concluded that dismissing information regarding occupational activity may miss important information (Evenson, Rosamond et al. 2003). Furthermore, in a prospective Canadian study examining the relation between physical activity and mortality in women, Weller *et al.* stated that the inverse relations they saw were due mainly to the contribution of household (domestic) physical activity which represented 82% of the women's total activity on average; thus illustrating that inclusion of non-leisure time energy expenditure is critical to the assessment of total physical activity (Weller and Corey 1998). Domestic energy expenditure is a source of activity that is rarely studied, but decreases could potentially contribute to increases in overweight and obesity. Notably, Lanningham-Foster *et* al. empirically measured the energy expended during common household chores, both with and without labor saving devices, and concluded that the energy saved by mechanization was sufficiently great to contribute to positive energy balance (Lanningham-Foster, Nysse et al. 2003). Although each labor-saving device may reduce physical activity only slightly, in sum these energy savings accumulate and may have a significant impact on total energy expenditure.

Physical activity from active transportation is also an important source of activity that should not be overlooked. Evidence from ecological data and from the urban planning and design discipline suggests that motorization contributes to obesity and that the proliferation of motorized transport in affluent countries has coincided with the increasing prevalence of obesity (Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004). In fact, in the developing world in general and China in specific, leisure time activity is not the predominant source of physical activity for adults; rather, the majority of energy expenditure is accumulated in occupational and transportation physical activity (Xu, Niu et al. 1997; Bell, Ge et al. 2001; Tudor-Locke, Ainsworth et al. 2001; Bell, Ge et al. 2002; Monteiro, Conde et al. 2003). Consequently, ignoring these important sources may lead to incomplete assessment. In this research we studied multiple types of physical activity including occupational, leisure time, transportation, and domestic, in order to further our understanding of the role that overall physical activity plays in the development of overweight and obesity.

3. Environmental and individual correlates of physical activity

In the United States, National surveillance data indicate only about 22% of adults meet recommended physical activity guidelines and, further, that 24% report being completely sedentary in their leisure time (Pate, Pratt et al. 1995). Sociodemographic characteristics are associated with physical activity patterns and choices. For instance, leisure time physical activity participation is consistently higher in men than in women and is inversely associated with age. Further, socioeconomic status appears to be a consistent determinant, with higher incomes and education levels predicting higher levels of recreational activity (Trost, Owen et al. 2002). Being overweight or obese is a negative predictor of physical activity, and African Americans and other ethnic minorities are less active than white Americans (Williamson, Madans et al. 1993; Pate, Pratt et al. 1995; Lewis, Smith et al. 1997). While these characteristics appear to be fairly consistent in developed countries, it is important to keep in mind that correlates are population-specific. Additionally, assessments have again primarily been done assessing only leisure time activity.

Over and above individual-level predictors, understanding the effect that environmental factors have on physical activity behaviors is an area of recent interest, and there has been important research examining neighborhood effects on the physical activity patterns of both adults and children (Craig, Brownson et al. 2002; Duncan, Duncan et al. 2002; Ewing, Schmid et al. 2003; Fisher, Li et al. 2004; Molnar, Gortmaker et al. 2004). Environmental correlates with physical activity range from neighborhood characteristics (such as presence of sidewalks, perceived safety, and land-use mix) to season and geographic region (Owen, Leslie et al. 2000; De Bourdeaudhuij, Sallis et al. 2003; Reis, Bowles et al. 2004). Investigations assessing the environmental effects on activity tend also to primarily explore leisure time activity, but a number of studies have been done looking at the effect of environmental characteristics on transportation via walking or bicycling (Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Owen, Humpel et al. 2004; Wendel-Vos, Schuit et al. 2004). Environmental research has primarily been made possible by advances in statistical modeling techniques such as multilevel analysis which are becoming more widely available and offer methods to quite elegantly disentangle individual- from environmental-level effects (Duncan, Jones et al. 1998; Kreft and De Leeuw 1998; Snijders and Bosker 1999; Diez Roux 2001; Cooper, Kaufman et al. 2003; Diez Roux 2004). Nonetheless, although there is consensus that environmental factors are likely to play an important role in physical activity behaviors and subsequent obesity, empirical evidence remains mostly unclear and further research is necessary (Crawford and Ball 2002; Humpel, Owen et al. 2002). Indeed, while multilevel analyses are becoming more widespread in the US literature, they are still uncommon from the developing country perspective. In this research we employed a sophisticated 3-level random-intercept multilevel model and thus were able to address two important gaps in the literature: (1) investigating the effect of both individual- and environmental-level factors on occupational physical activity levels, and (2) doing so in the developing-country setting.

C. Physical activity in China is different than in the developed world

Physical activity arises from a number of different sources, including household activities, occupational activities, leisure time activities, and active transportation. Although complete physical activity profiles of Chinese adults have not fully been undertaken, previous research has shown that ownership of a motor vehicle significantly increases the odds of being overweight and having increased waist circumference in men (Bell, Ge et al.

2002). Vast shifts in the occupational structure of China in the last 20 years have resulted in fewer jobs reliant on physical labor and increasing use of technological innovation, especially in urban areas (Popkin, Paeratakul et al. 1995; Zhou, Li et al. 2003; Friedman 2005). We hypothesized that these shifts coincided with increases in overweight and obesity. Evidence indicates that reductions in occupational physical activity alone are associated with increases in overweight and obesity among adult Chinese men and women (Paeratakul, Popkin et al. 1998; Bell, Ge et al. 2001). In this research, we sought to further quantify overall physical activity profiles by incorporating multiple sources of adult activity and thus expand upon the earlier results using these data. Physical activity in China is very different than in the developed world and evidence suggests that while the prevalence of leisure time activity is very low, both active commuting and occupational activity are highly prevalent (Bell, Ge et al. 2001; Bell, Ge et al. 2002; Hu, Pekkarinen et al. 2002; Hu, Pekkarinen et al. 2002). In fact, very few people own private cars (although numbers are growing) and China is the largest bicycle-using country in the world (Hu, Pekkarinen et al. 2002). Nonetheless, it is possible that in response to rapid economic development, increasing urbanization, and declining physically demanding occupations, these trends may start to shift. Our research examines trends in multiple domains of physical activity in Chinese adults, including those from the leisure, occupation, domestic, and transportation sources. We hypothesized that over time and with increasing urbanization we would observe decreases in the amount of transportation, occupational, and domestic physical activity, concomitant with a rise in the prevalence of overweight and obesity.

1. Overweight and obesity in China

The average BMI values and prevalence of overweight and obesity in the Chinese population are much lower than age- and gender-matched values in western populations. One large population-based sample of 35-59 year-olds reported a mean BMI of 22.5 for men and 23.1 for women; the prevalence of overweight and obesity, respectively, for men was 20.7% and 1.5%, and for women was 27.0% and 3.9% (Zhou, Wu et al. 2002). In a further random sample of urban adults over 20 years of age from Shanghai, researchers observed that 29.8% of the men and 30.7% of the women had BMIs between 25 and 29.9 kg/m^2; while BMI values of ≥ 30 kg/m^2 were observed in 2.3% of men and 5.5% of women (Jia, Xiang et al. 2002). Trend data from Chinese national nutrition surveys from 1982 to 1992 show that the prevalence of overweight (≥ 25 kg/m^2) has increased in urban young adults from 9.7% to 14.9% and in rural young adults from 6.2% to 8.4% (Tee 2002). In contrast, recent data from the National Health and Nutrition Examination Survey report the age-adjusted prevalence of obesity in the United States at 30.5% and overweight at 64.5% (Flegal, Carroll et al. 2002). Despite the reduced prevalence of overweight and obesity among Chinese adults in comparison to the United States, the numbers are rising dramatically and are very large in absolute numbers given China's large population. More importantly, accumulating evidence indicating a high prevalence of type 2 diabetes and increased cardiovascular risk factors in parts of Asia where the average BMI is below the accepted cut-off point of 25 kg/m^2 for adult overweight according to the World Health Organization (WHO 1995), as well as increasing evidence that for a given BMI Asians have a higher percentage body fat, has raised concerns that the current WHO BMI cut-off points underestimate obesity-related risks in Asian populations (McNeely, Boyko et al. 2001; Bei-Fan 2002; Li, Chen et al. 2002; Zhou 2002; Rosenthal, Jin et al. 2004). This analysis does not enter into the debate regarding BMI cut-off points; however, an increase in CVD risk factors is of public health significance and was of interest to our investigations, especially as a decline or reversal of the present trends is not expected.

2. The nutrition transition and urbanization in China

Countries undergoing the nutrition transition display rapid changes in diet and lifestyle resulting from urbanization, industrialization, and economic development with a concomitant impact on the nutritional status of their populations (Popkin 2001; Popkin, Horton et al. 2001; Popkin in press). Obesity, diabetes mellitus, cardiovascular disease, hypertension, and various forms of cancer are displacing more traditional public health concerns like malnutrition, undernutrition, and infectious disease (Popkin 1998; Popkin 2001). Of further concern is the notion that emerging economies such as China's experience the nutrition transition much sooner and at a lower level of Gross National Product than that seen in western societies (Drewnowski and Popkin 1997; Popkin 2001), at times resulting in the double-burden of simultaneous undernutrition and overnutrition within a household (Popkin, Paeratakul et al. 1995; Doak, Adair et al. 2002; Florentino 2002; Doak, Adair et al. 2005). An additional characteristic observed in countries undergoing the nutrition transition is that the prevalence of overweight and obesity is tied to a country's level of socioeconomic transition; at the beginning and middle stages of the transition, rates are generally higher in urban than in rural areas, and in higher socio-economic groups of the population (Popkin, Paeratakul et al. 1995; Florentino 2002; Kim, Symons et al. 2004). Further, there is recent evidence that the burden of obesity is shifting to those of lower socioeconomic status in lower-middle income or upper-middle income developing countries (Monteiro, Conde et al.

2004; Popkin and Gordon-Larsen 2004). China is still regarded as a low income economy, and as expected, rates of overweight and obesity are highest in urban populations and those of higher income (Popkin, Paeratakul et al. 1995; Du, Lu et al. 2002; Kim, Symons et al. 2004). However, recent evidence indicates that the prevalence of obesity is higher among Chinese adults with less education as compared to those with more education (Monteiro, Conde et al. 2004), and thus depending on which indicator of socioeconomic status is selected, China's underprivileged may be at risk.

Urban-rural disparities are a major field of study in public health, in both the developed and developing worlds, and studies have reported both positive and negative health outcomes with urban living (Verheij 1996; McDade and Adair 2001; Torun, Stein et al. 2002; Sobngwi, Mbanya et al. 2004). And while urbanicity is one of the most commonly used ecological variables in studies of health, the mechanisms behind the relationship are not well understood (Verheij 1996), likely due in part to difficulties and diversity in measurement and classification. Nonetheless, rapid urbanization is a major part of the nutrition transition and urban residence is an important predictor of overweight and obesity in many developing countries, including China (Popkin and Doak 1998; Qu, Zhang et al. 2000; Adair 2004; Lee 2004; Popkin and Gordon-Larsen 2004). Urban-rural differences in nutritional status are due to, among other factors, better transportation and marketing systems in urban areas resulting in greater exposure to diverse food sources (Popkin 2001). Additionally, urban living is associated with reductions in overall energy expenditure (Caballero 2001; Kruger, Venter et al. 2003), suggesting that countries undergoing urbanization may be at risk for increasing levels of inactivity (Lambert, Lambert et al. 2001). Declines in physical activity concomitant with increases in urbanicity could be due to shifts in occupational activity, away from more labor intensive jobs toward more sedentary service sector jobs, and reductions in energy expenditure even within job type due to increases in mechanization and technology implementation. Further, modern urban infrastructure such as roads, motorized transport, increases in television programming availability, and increased use of labor-saving devices for domestic work could hypothetically lead to decreases in overall energy expenditure and increases in sedentary behaviors. However, studies investigating the direct effects of urbanization on physical activity and overweight are lacking. Assessing these relationships as China undergoes the nutrition transition was of primary interest to us. In these analyses we utilized a multidimensional measure designed specifically for the CHNS to capture urbanization and urbanicity from the physical, social, cultural, and economic environments (Mendez and Popkin 2005). The urbanization variable was developed from community-level information on housing, transportation, and communication infrastructures, sanitation, health care services, schools, markets, economic indicators, and population size and density. Measurement of urbanization in this manner is advantageous not only in that it allows for a more meaningful classification of communities rather than the traditional urban/rural dichotomy, but also the time-varying quality of the index allows us to explore changes in urbanization over time.

D. Summary and significance

In summary, China is in the midst of an enormous economic transition that is expected to have serious consequences on the nation's public health. Increases in urbanization and other changes in the environment have already brought along increases in overweight and non-communicable chronic disease such as type 2 diabetes and cardiovascular disease to the adult population. The role that changing dietary patterns play in these increases has been studied to some extent; however, we have yet to fully characterize the overall physical activity behaviors of China's adults and understand the role they play. In this research we seek to add to the basic knowledge about physical activity, its determinants, and effects, by assessing multiple important sources of activity including time spent in leisure, occupation, transportation, and domestic duties. This alone is substantially different than the majority of research where activity is studied using only one domain, typically leisure time activity. Indeed, because leisure time activity is not highly prevalent in China, failing to assess activity from the transportation, occupational, and household sources could result in lack of finding an effect where one may be operating.

In this research we assessed the correlates of physical activity behaviors from both individual and environmental perspectives with sophisticated modeling techniques that are underused in the developing country context. Research has shown that environment plays an important role in an individual's physical activity, yet these relationships have not been systematically explored in countries undergoing transition. China's rapidly changing environment and increasing urbanization allowed for in-depth analysis of the specific effect that these changes are exerting on the individuals who live within them.

Our ability to use longitudinal data in investigating the role physical activity plays in the increase in overweight is a substantial strength of this research. There is a notable lack of longitudinal data from developing countries and nations in transition; rather, it is largely cross-sectional. Even so, previous research suggests that communities undergoing transition face reduced physical activity levels and that these reductions are associated with increased overweight and morbidity from non-communicable diseases. It is necessary for us to have longitudinal studies that support these data and allow for time-dependent associations to emerge. This research specifically addresses this deficiency and furthers the understanding of the relationship between physical activity and overweight, as well as helps to quantify the way that factors such as urbanicity and socioeconomic status may act as determinants.

We recognized that teasing apart the physical activity – obesity relationship is a difficult task because of the complex causal web that is likely involved. However, by approaching it in a specific contextual environment with the appropriate methods, we were able to further current understanding. The China Health and Nutrition Survey with its socioeconomically and demographically diverse sample provided us with a unique opportunity to understand the nature of physical activity in a developing country in transition and the important consequences for the public's health.

III. Methods

A. Survey design: The Chinese Health and Nutrition Survey

1. Overview of survey design and sample

The Chinese Health and Nutrition Survey is an ongoing, longitudinal study of a socioeconomically and demographically diverse sample of the Chinese population. The survey was designed to examine the effects of health, nutrition, and family planning policies and programs implemented by national and local governments, and to investigate how the social and economic transformation of Chinese society is affecting the health and nutritional status of its population. A multistage, random cluster process was used to draw the sample surveyed in each of eight selected provinces. Counties in the eight provinces were stratified by income (low, middle, high) and a weighted sampling scheme was used to randomly select four counties in each province. Additionally, the provincial capital and a lower income city were selected. Villages and townships within the counties and urban and suburban neighborhoods within the cities were selected randomly for a total of 190 communities (32 county capitals, 30 suburban neighborhoods, 32 urban neighborhoods, 96 villages). At this writing, six rounds of data have been collected: 1989, 1991, 1993, 1997, 2000, and 2004. Data collected in 1989 and 2004 were not used in these analyses due to differences in the questionnaire on key variables and unavailability, respectively. Detailed data were collected at three levels: individual, household, and community. All household members provided individual-level data on dietary intake, body composition, health history, and health-related behaviors; household-level data were collected on economic activities, income, and assets; community-level data were collected from a knowledgeable respondent on community infrastructure, services, population, wages, and related variables.

2. Exclusions

The sample utilized for all aims excluded all participants under the age of 18 and over the age of 55. We have selected 55 as our age cut point in order to avoid issues of retirement, which typically occurs around this age, and thus proactively avoid changes in activity due mainly to this life change. The lower cut point of 18 is the age at which men and women typically enter the workforce and take on adult responsibilities. For all aims we excluded pregnant women and individuals in poor health or with significant disability that might have influenced their weight status or ability to participate in physical activity.

B. Measurement of key variables

1. Occupational physical activity

Occupational physical activity was derived from an in-depth interview in which respondents were asked about the activity required in their occupation(s) including standing, sitting, lifting, etc. Respondents were then categorized as having very light to very heavy occupational activity. Earlier studies using these data have successfully condensed these categories into light (very light + light), moderate, or heavy (heavy + very heavy) activity, and these three categories were used for our assessment of occupational activity in aim1.

Energy expenditure data for aims 2 and 3 were derived from multiple questions in reference to wage work including occupations both outside and inside the home. Categories included working on a farm, working in a vegetable garden or orchard, raising livestock or poultry, work fishing, working in a home business, and work from up to two “traditional” market-based jobs (e.g. working in an office, as a policeman, in construction, etc.). Respondents were asked the average number of hours per week in the last year spent in the specified activity. Time spent in each occupational activity category was multiplied by a specific metabolic equivalent (MET) intensity value, for a final value in units of MET-hours/week. We assigned MET values to specific occupations using the self-reported measure of work intensity (“force”). Next, for each specific occupation, we assigned MET values of 2, 4, and 6 to occupations reported as light, moderate, and heavy, respectively, based on how the majority of respondents were classified with respect to their self-reported occupational activity. Farming, fishing, or working in a garden/orchard were overwhelmingly reported as being high intensity occupations; those working in livestock were more varied, but the majority still reported high occupational activity. Thus, these activities were given a MET value of 6 (heavy). MET values of 2 (light) were given to those working in a home business, working as a senior or junior professional, working as an administrator, executive, manager, or office staff, and working as an army officer or police officer; MET values of 4 (moderate) were given to those working as a skilled worker (foreman, group leader, craftsman), as a non-skilled worker (ordinary laborer, logger), and as a driver, homemaker, or student. Individual MET-hours per week values were then summed to obtain a measure of overall occupational activity energy expenditure.

2. Domestic (household) physical activity

For aim 2, domestic physical activity was measured using four different activities that were available in all 1991. 1993, 1997, and 2000: time spent preparing food, buying food, doing laundry, and time spent in childcare. For aim 3 we added time spent cleaning house which was available in the 1997 and 2000 survey years. All activities were reported in average hours per week spent in the last year.

To create a measure of energy expenditure for domestic activities, we again multiplied the time spent in each domestic activity category by a specific MET intensity value for a final value in units of MET-hours per week. For specific MET intensity values we utilized the Compendium of Physical Activities (Ainsworth, Haskell et al. 2000), assigning a MET value of 2.25 to preparing food, 2.3 to buying food, 2.15 to doing laundry, and 2.75 to childcare. Individual MET-hours per week values were then summed to obtain a measure of overall domestic activity energy expenditure.

3. Transportation physical activity

Transportation activity data (aim 3) were derived from questions asking the round-trip commuting time to/from work, school, and/or shops via foot or bicycle. Because most individuals in China work a 6-day work week, we assumed a value of 6 days/week to calculate hours/week spent walking and/or bicycling for transportation purposes. Hours spent per week were multiplied by specific MET intensity values (3.5 for walking, 4.0 for bicycling) from the Compendium of Physical Activities (Ainsworth, Haskell et al. 2000) to assess energy expenditure.

4. Leisure time physical activity

In the literature, leisure time physical activity refers to physical activity done in one's leisure, or free, time, and often denotes exercise or sport participation. Leisure time activity data were collected for the first time in the 1997 wave of the CHNS, with the first follow-up data collected in 2000. Individuals over 18 years in the CHNS were asked the average weekly time spent over the last year in the following sports and recreational activities more common in China: martial arts; jogging or swimming; dancing or acrobatics; basketball, volleyball, or soccer; and badminton, tennis, or ping pong. Because sports and recreational activities were condensed into categories, to calculate energy expenditure we used the Compendium (Ainsworth, Haskell et al. 2000) to calculate a mean MET value for each category (10.0 for martial arts, 7.0 for jogging or swimming, 5.25 for dancing or acrobatics, 6.3 for ball sports, and 5.2 for racquet sports). Individual MET-hours per week values were then summed to obtain a measure of overall leisure activity energy expenditure.

5. Anthropometric measures

Anthropometric data were collected by trained health workers during a comprehensive physical exam. Height was measured without shoes to the nearest 0.2 cm using a portable stadiometer; weight was measured without shoes and in light clothing to the nearest 0.1 kg on a calibrated beam scale. BMI (calculated as weight in kilograms divided by the square of height in meters) was used continuously and also to define overweight and obesity relative to the World Health Organization and the International Obesity Task Force BMI cutpoints of 25 and 30, respectively. Individuals were also categorized as weight gainers if they gained ≥3% body weight, weight losers if they lost ≥3% body weight, and weight maintainers if they gained and/or lost within 3% of body weight (Stevens, Truesdale et al. 2005).

6. Individual-level variables

Non-anthropometric data relevant to the individual-level include gender, education (number of years completed), and age (in years). Dietary data were obtained via three consecutive days of 24-hour recall from which measures of total energy intake were computed using official Chinese food composition tables.

7. Household-level variables

Certain data were collected at the level of the household, not at the individual level. Relevant variables include deflated household income per capita, which includes multiple components such as occupational income, farm income, and subsidies, and assets, such as ownership of various labor-saving household devices. Data collected at the household level were assigned to each member of the household as an individual-level variable rather than aggregated and analyzed as an upper-level variable in multilevel models.

8. Community-level variables

Earlier analyses using the CHNS data have indicated that urbanicity is an important correlate and/or predictor of the nutritional behaviors in which we are interested. In an effort to gain further understanding of the important as well as changing role that urbanicity plays and will continue to play in China, a scale has been developed to more fully characterize the level of urbanization in a given sampled area. This urbanization index was based on data from 190 sampled communities on the following 10 components: communication infrastructure, economic infrastructure, availability of schools, environmental sanitation, population, population density, quality/availability of health care, housing-related infrastructure, availability of markets, and transportation infrastructure. Each component contributes up to a maximum of 10 points to the overall 100-point measure. At the time of this research, the index was available for the 1989, 1991, 1993, and 1997 survey years. 1989 data were excluded for other reasons, as specified earlier.

IV. China's Transition: Measuring the Dimensions of Urbanization Captures Major Shifts in Adult Physical Activity Patterns

A. Introduction

China has undergone tremendous urbanization and economic development over the last few decades. According to the year 2000 census, the urban population has reached a staggering 459 million people (36%) and continues to grow at rate of 4.7 percent annually, arising from rural to urban migration, urban reclassification, and urban natural increase (Friedman 2005). China has seen remarkable changes in terms of infrastructure, land use, transportation planning, urban design and in other important ways (Popkin 2001; Popkin 2002; Friedman 2005). Growth in technology and information capabilities has necessitated significant structural transitions in employment and altered the occupational landscape, with a major shift from agricultural employment to industrial, commercial, or service-based employment (Popkin, Paeratakul et al. 1995; Popkin 2001; Zhou, Li et al. 2003). Concomitant with these shifts is the transition away from labor intensive occupational activity to jobs that are more sedentary.

Occupational activity is a major source of activity for adults in China, since leisure time activity and sports have not become prevalent means of exercise as they have in more developed nations (Bell, Ge et al. 2001; Bell, Ge et al. 2002; Hu, Pekkarinen et al. 2002; Hu, Pekkarinen et al. 2002; Fu and Fung 2004); therefore this shift may portend the removal of an important source of physical activity for Chinese adults. Relevant to this we note that China has recently had a remarkable increase in the number of overweight adults. Urban residence is an important predictor of overweight and obesity in many developing countries, including China (Popkin and Doak 1998; Qu, Zhang et al. 2000; Adair 2004; Lee 2004; Popkin and Gordon-Larsen 2004), and it is possible that one mechanism through which this is operating is the decreasing occupational activity of its residents. Thus, as the trend of increasing urbanization continues it is important for researchers to be aware of the public health significance of such shifts, as they are likely to play a large role in the overall health of individuals.

In attempts to broaden our understanding of the determinants of physical activity, hypotheses have emerged that acknowledge the importance of environmental-level influences. Understanding the effect that environmental factors have on physical activity behaviors is an area of recent interest and there has been important research examining neighborhood effects on the physical activity patterns of both adults and children (Owen, Leslie et al. 2000; Ross 2000; Craig, Brownson et al. 2002; Duncan, Duncan et al. 2002; Humpel, Owen et al. 2002; Diez Roux 2003; Ewing, Schmid et al. 2003; Fisher, Li et al. 2004; Molnar, Gortmaker et al. 2004). Investigations assessing the environmental effects on activity tend to primarily explore recreational or leisure time activity (De Bourdeaudhuij, Sallis et al. 2003; Humpel, Marshall et al. 2004; Reis, Bowles et al. 2004; Li, Fisher et al. 2005), as well as transportation activity via walking or bicycling (Bell, Ge et al. 2002; Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Owen, Humpel et al. 2004; Wendel-Vos, Schuit et al. 2004). To our knowledge there have been no earlier studies examining the effect of specific environmental characteristics on occupational physical activity. This lack may be partly attributable to the fact that the majority of this body of research focuses on the developed world where occupational activity patterns are less dynamic than in countries where rapid urbanization and development is occurring.

Our purpose was to determine the effect that urbanization in China has on the occupational physical activity patterns of adults. We hypothesize that increases in urbanization of the Chinese landscape have had a marked impact on the amount of occupational physical activity. Declines in physical activity concomitant with increases in urbanicity could be due to shifts in occupational activity, away from more labor intensive jobs toward more sedentary service sector jobs, and reductions in energy expenditure even within job type due to increases in mechanization and technology implementation. Using a multilevel approach, we investigated community-level urbancity as an independent risk factor for declining occupational activity in a longitudinal sample of Chinese adults while accounting for individual-level predictors. This study takes advantage of a detailed measure of urbanization developed specifically for our sample that assesses multiple components of infrastructure and socio-economic development.

B. Methods

1. Study population

Data were derived from the China Health and Nutrition Survey, an ongoing, longitudinal study of a socioeconomically and demographically diverse sample of the Chinese population ideally suited to examine how the social and economic transformation of Chinese society is affecting the health and nutritional status of its population. Briefly, in each of eight provinces varying substantially in geography, economic development, as well as other indicators, multistage random sampling was used to select communities from the capital city and a smaller city as well as from four economically diverse rural counties (one low-, two middle-, and one high-income). Twenty randomly-selected households were interviewed in each community. Further details regarding the sampling scheme are given elsewhere (Popkin, Paeratakul et al. 1995; Paeratakul, Popkin et al. 1998; Bell, Ge et al. 2001).

Longitudinal data on 4376 men and 4384 women between the ages of 18 and 55 who participated in the 1991, 1993, or 1997 CHNS were used for these analyses. Each individual provided information for between 1 and 3 measurement occasions corresponding with waves of data collected in the three survey years, resulting in 8518 and 8694 total responses for men and women, respectively. Pregnant or breastfeeding women as well as any individuals missing information on occupational activity or any of the predictor variables within a survey year were excluded. By wave, total individuals excluded due to missing data and/or due to being pregnant or breastfeeding numbered 523 for 1991, 571 for 1993, and 1955 for 1997. The individuals were clustered within 189 communities each of which included between 6 and 72 individuals, with a mean of 35.5 individuals per community. Only three communities had fewer than 10 individuals in them.

2. Dependent variable

Adult respondents were interviewed about the activity required in their occupation(s) including standing, sitting, lifting, etc. They were then categorized as having very light to very heavy occupational activity. The five categories were collapsed into three indicating light, moderate, and heavy occupational activity. Examples of occupations representing these categories are "office worker" for light, and "farmer" or "construction worker" for heavy. Models were first run using this 3-level categorical variable; however, upon testing each individual coefficient using a pooled dataset and clustering on the outermost level (community), we found that the moderate and light categories were not different from each other. Thus, these categories were collapsed to form a dichotomous variable indicating light or moderate ("light" from this point forward) vs. heavy occupational activity. In all analyses, heavy activity was used as the referent category.

3. Community level variable – key exposure

Urban-rural disparities are a major field of study in public health, in both the developed and developing worlds, and studies have reported both positive and negative health outcomes with urban living (Verheij 1996; McDade and Adair 2001; Torun, Stein et al. 2002; Sobngwi, Mbanya et al. 2004; Galea and Vlahov 2005). Urban health researchers often differentiate between "urbanization," referring to the process of a place becoming urban, and "urbanicity," referring to the extent to which a place is urban or rural (Verheij 1996; Vlahov and Galea 2002). In these analyses we utilize a multidimensional measure designed specifically for the CHNS to capture urbanization and urbanicity (hereafter "urbanization") from the physical, social, cultural, and economic environments (Mendez and Popkin 2005). The urbanization variable was developed from community-level information on housing, transportation, and communication infrastructures, sanitation, health care services, schools, markets, economic indicators (e.g. average wage for a male worker), and population size and density. The data were used to generate an urbanization score for each community for each data collection period (maximum value=100 points), with higher values indicating a higher degree of urbanization. The index is advantageous not only in that it allows for a more meaningful classification of communities rather than the traditional urban/rural dichotomy, but also the time-varying quality of the index allows us to explore changes in urbanization over time. More information on the development of the urbanization index can be found elsewhere (Mendez and Popkin under review). For our sample at baseline (1991) the mean index value was 50.4 and ranged from 18.6 to 84.4. By 1997 the average index was 55.0, ranging from 21.1 to 89.4. Urbanization was included as a higher-level continuous variable in statistical models.

4. Individual-level (confounding) variables

All analyses were stratified by gender because overall factors influencing physical activity tend to differ for men and women, and further, in China, the occupational environment is very different for men and women. Age, age-squared, and age-cubed were used to model the observed curvilinear (J-shaped) relationship between age and occupational activity in the data. Light occupational activity decreased from young through middle adulthood and then increased again in later adulthood (approaching retirement age) for both men and women. Individual income included the sum of all sources of income and was divided into tertiles according to annual per capita household income, comparing low income to middle or high income categories. Education was categorized as having a primary school education or less, a middle school education, and a high school or college education. Time was coded categorically for the three separate waves of data collection in 1991, 1993, and 1997, with wave 1991 used as the referent category. We also tested smoking status (yes/no) and self-reported health status (good, fair, poor), but they were found to not significantly alter the estimates and were excluded from the final models.

5. Statistical analysis

Data were collected over time at both the individual and community levels. Multilevel modeling (also called hierarchical linear modeling) provides a framework with which we can assess the effects of covariates measured at different levels of the hierarchy on the outcome. Further, because it accounts for the clustering of data, multilevel modeling corrects the biases in parameter estimates and provides correct standard errors and thus correct confidence intervals and significance tests (Von Korff, Koepsell et al. 1992; Guo and Zhao 2000).

For the present study we used a three-level logistic random intercept multilevel model with measurement occasions (level 1) nested within individuals (level 2) and communities (level 3). Using this strategy we constrain the effect of urbanization on individual occupational activity (i.e. the slope) to be the same across all communities; however, the "starting point" (i.e. the intercept) is allowed to vary between communities, and is modeled with a random quantity which applies to all individuals clustered in the same community. This model is justifiable because it is plausible to assume that, regardless of community, the same ingredients for urbanization are likely to result in similar occupational activity opportunities for residents.

The multilevel model is described by the series of equations outlined below. In the logistic regression setting the first level equation for the probability of light occupational activity is defined as:

$$(1)\ \text{logit}\,(Y_{tij}) = \pi_{0ij} + \pi_{1}(TIME)_{tij}$$

where the indices t, i, and j are used to denote measurement occasions, individuals, and communities, respectively. π_{0ij} represents the initial status of individual ij; *TIME* represents indicator variables denoting waves 1993 and 1997 in reference to baseline wave 1991; and the coefficients π_1 represent the change in the log odds of light occupational activity.

We next add in individual-level predictors which may explain variation in occupational activity. The second level equation is as follows:

$$(2)\ \pi_{0ij} = \beta_{0j} + X_{tij}\,\beta_1 + r_{ij}$$

where β_{0j} represents the mean initial occupational activity within community j; X_{tij} represents a matrix of time-variant predictor variables (e.g. income, education, age); the coefficients β_1 represent the "gap" in initial occupational activity between the referent group and the indicated group within community j for income and education, and the expected change in the log odds of light occupational activity given a one year increase in age; and r_{ij} is the random intercept for subject i in community j, which varies at level 2.

Given observed upper-level variance with respect to occupational activity, we next address predictors at the community level that may "explain" group-level variation in the intercept. The third-level equation is defined as follows:

$$(3)\ \beta_{0j} = \gamma_0 + Z_{tj}\gamma + \mu_j$$

where γ_0 represents the overall mean initial occupational activity for an individual of low income, no school/primary school education level, of average age, and living in a community of average urbanization; Z_{tj} represents time-varying community-level variables, which in our case is the continuous urbanization index measure; the coefficient γ represents the expected change in the log odds of light occupational activity given a one-unit change in urbanization;

and μ_j is the random intercept for community *j*, which varies at level 3 and represents place differences after controlling for individual-level predictor composition.

Substituting equation 3 into 2 and 2 into 1, the final model for the probability of light occupational activity is defined as follows:

$$(4)\ \text{logit}\,(Y_{tij}) = \underbrace{\gamma_0 + \pi_1(TIME)_{tij} + X_{tij}\,\beta_1 + Z_{tj}\gamma}_{\text{Fixed effects}} + \underbrace{r_{ij} + \mu_j}_{\text{Random effects}}$$

A fully unconditional (only time was included, no individual- or community-level predictors were) model was fit first, providing us with an indication of how variation in occupational activity is allocated across the levels (Bryk and Raudenbush 1992). Including time in this model should not alter the variance structure of the outcome because time is not clustered within communities. Evidence of between-person and between-community variation at this step justifies our addressing individual-level and community-level predictors that may "explain" variation in the intercept (Bryk and Raudenbush 1992; Diez Roux 2004; Wright, Bobashev et al. 2005). Thus, we first introduced the individual-level predictors income, education, and age, followed by the community-level variable urbanization. Cross-level interactions between urbanization and education, urbanization and income, and urbanization and age were tested during model building to evaluate whether the effects of community-level characteristics differ by demographic characteristics of residents. We further tested the interaction between urbanization and time to evaluate whether the impact of urbanization on the outcome was different by time period. Nested models were compared using the difference between the deviances as a likelihood ratio statistic, which has an approximate χ^2 distribution and indicates whether one model is a significant improvement over the other (Kreft and De Leeuw 1998; Guo and Zhao 2000). Interaction terms were included in the final model only if they improved the model fit significantly. Generalized linear mixed models were operationalized using the GLLAMM program (www.gllamm.org) within Stata/SE version 8.2, which estimates parameters using adaptive Gaussian quadrature (Rabe-Hesketh, Skrondal et al. 2002).

C. Results

1. Population characteristics

At baseline, all individual- and community-level characteristics were associated with level of occupational activity, most notably income, education level, and community-level urbanization quartile (Table 1). Overall, the proportion of men and women with light occupational activity was about equal and increased with increasing level of income, education, and urbanization. Heavy occupational activity was highest in the mid-adult years. In the follow-up years of 1993 and 1997, the majority of shifts were from heavy to light occupational activity.

In tables 2 (males) and 3 (females), we show results for nested models in which additional parameters were subsequently added to the fully unconditional model (Model 1). This preliminary model indicated a significant variance in occupational activity at both the individual and community levels, implying that further investigation of hypothesized covariates was warranted in attempts to explain this variance.

2. Fixed effects: Individual main effects

Individual-level fixed effects are interpreted as the average effect of the variable across communities. Light occupational activity increased in a dose-response manner in both sexes with increasing education and income and was the most prevalent among younger workers, increasing again as retirement age approached (model 3). The relationship with time, however, differed by gender, with null results for men at 1993 and 1997 versus baseline after controlling for individual- and group-level predictors. However, for women light occupational activity in 1991 was significantly more than that in 1993 and significantly less than levels in 1997, indicating a j-shaped relationship.

The wave variables represent the time-associated effect of urbanization not picked up by the other time-varying variables in the model. In the case of males, the time-varying variable urbanization picked up the majority of the time effect for men. For women, however, the significant relationship between time and occupational activity indicates that the urbanization index may not similarly capture the variability surrounding occupational activity. Thus, urbanization may not have as marked an effect on women's versus men's occupational activity, possibly due to differences in job structures and participation in the labor force for men and women in China.

3. Fixed effects: Community main effects

Tables 2 and 3 also show the results from the fixed effects for the community-level predictor of occupational activity. For both men and women, after adjustment for individual-level predictors, the contextual variable urbanization was strongly associated with occupational activity (fixed effects, model 3), with a one unit change in urbanization resulting in a 7% (males) and 6% (females) increase in the risk of light occupational activity. Given that the mean change in urbanization between 1991 and 1997 in communities that were sampled at both time periods was 7.8 index points, this translates to an increase in risk of 68% for men and 51% for women.

Using predicted probabilities from model 3 (tables 2 and 3) it is clear that light occupational activity increased linearly with increasing urbanization (Figure 1), ranging from 24.5% (males) and 30.2% (females) at lowest to 72.0% (males) and 64.8% (females) at highest urbanization index. Therefore there was a 47.5% and 34.6% higher chance of having light occupational activity for men and women, respectively, given residence in the most urban versus the most rural communities.

4. Cross-level interaction effects

As a final step, we included cross-level interactions between urbanization and all individual-level variables to determine whether the effect of urbanization differed by individual characteristics. We found no evidence of significant interaction between any individual-level variable and urbanization for women; however, for men there was evidence of a significant interaction between urbanization and age (Table 2, model 4). We further tested the interaction between time and urbanization and found no significant result for either men or women. This suggests that urbanization's effect on occupational activity is not increasing (nor decreasing) over time; rather, that during the time period we sampled (1991-1997) this relationship was constant.

5. Random effects

Model 1 is clearly underspecified, meaning it contained no explanatory variables, but it allowed for exploration of community-level variability in occupational activity. In both men and women we observed a significant level of extra-individual variability and thus can reasonably address predictors that may "explain" group-level variation in the intercept. First, however, we add individual-level predictors that may account for some of these differences (model 2) because variation may arise not because place *per se* is important, but because individuals with certain characteristics (e.g. higher income or education) may cluster in select communities and give rise to spatially differentiated population compositions. There was a decline in community-level variation with the addition of individual-level predictors, which explained 29% and 21% of the variation for men and women, respectively, indicating community-level population differences. Using a goodness-of-fit test based upon the difference in the deviance between the two models we are not surprised to see that model 2 was a significantly better fit than model 1 (χ^2=377, p<0.001). Nonetheless, there was still a substantial amount of residual community-level variation, and upon adding the urbanization measure we saw an additional, and larger, decline in community-level variance. After controlling for individual-level factors, community-level urbanization explained 54% and 40% of variance in occupational activity for men and women, respectively. As further evidence that urbanization was an important predictor of occupational activity, we note that including it led to a substantial reduction in the likelihood (χ^2=52, p<0.001). The high intraclass correlation (ICC) values, as a measure of the similarity of people from the same community, indicated substantial clustering of occupational activity in community and a strong community influence on individual occupational activity for both men and women.

D. Discussion

Our results, based upon data from a diverse sample of Chinese adults, showed that community-level urbanization was importantly associated with occupational activity among men and women after adjustment for individual-level sociodemographic factors. In fact, after individual-level factors were accounted for, between-neighborhood differences explained over half of the total variability in occupational activity in this population for men, and 40% of the variability in women. Further, the measure of intraclass correlation indicates that in this sample of Chinese adults urbanization is a more important determinant of occupational activity than the individual factors that we assessed. Our results showed that for every one-unit increase in urbanization in a given community, men had a 7% and women a 6% higher chance of light occupational activity, which translates to an increase in risk of 68% for men and 51% for women. Given that there is no foreseeable decline of urbanization in China in the future, our results herald a dramatic decline in overall occupational activity, and potentially overall physical activity for the adult populous.

While occupational activity is studied less frequently than other forms of activity, such as that derived from sports or leisure time physical activity, a number of studies have demonstrated the importance of work as a source of energy expenditure (Dorn, Cerny et al. 1999; King, Fitzhugh et al. 2001; Evenson, Rosamond et al. 2003). In developed countries such as the United States, leisure time activity often substitutes for activity that is lost in occupational activity due to sedentary jobs (Evenson, Rosamond et al. 2003). However, leisure time activity is not yet common for the Chinese population studied here, thus it can be postulated that through the decline of work-related activity many adults will lose a substantial amount of their overall physical activity. Recent econometric research has examined the consequences of technological change on rising obesity incidence, partly through its effects on declining work-related physical activity (Lakdawalla and Philipson

2002; Philipson and Posner 2003). These studies, while not utilizing direct measurement of activity patterns by occupation such as those used in this study, find that occupational activity change is a key component of the increase in obesity seen in the United States. While it was not the purpose of this paper to examine the direct effect of technological change on the rising obesity rates in China, the important connection found between technological forces (as enacted through urbanization) and occupational physical activity, which we have shown to be an important determinant of weight in earlier work (Paeratakul, Popkin et al. 1998; Bell, Ge et al. 2001), is evidence of a possible connection between the two.

Our results show a monotonic increase in sedentariness in work with increased income and educational attainment for both men and women. It is of interest to note that while in developing countries lower socioeconomic status is protective against obesity (Philipson and Posner 2003; Monteiro, Conde et al. 2004; Popkin and Gordon-Larsen 2004), as urbanization continues and more individuals benefit from technological change and availability of higher paying, yet more sedentary jobs, we might expect not only the incidence of obesity to increase but also the burden of obesity to shift to those of lower socioeconomic status. We further see an interesting relationship between age and occupational activity, with younger workers being the most sedentary. Because the types of jobs that thrive in an urbanizing environment are often more technology-driven, they tend to draw a younger work force while those who are older when urbanization happens have a more limited skill set and are forced to continue in jobs requiring more physical labor. Of course, as workers age and approach retirement they again become more sedentary.

This study has a number of limitations. First the data used in the analyses were based on self reports, and thus potentially subject to reporting biases. Nonetheless, our measure of occupational activity is assessed for each individual in a manner that differentiates between people in the same occupation subgroup but with different activity patterns, and it has been successfully used in past analyses (Paeratakul, Popkin et al. 1998; Bell, Ge et al. 2001; Stookey, Adair et al. 2001). Furthermore, self report is still the most commonly used method in physical activity research (Sallis and Saelens 2000; Dale, Welk et al. 2002). Second, assessment at the community level may not be the most theoretically relevant level because the occupational environment may be quite heterogeneous within a community, especially if one lives on the outskirts or within the community center (Friedman 2005; Li, Fisher et al. 2005). Thus, a potentially better measure would be the immediate surrounding area which encompassed an individual's direct occupational opportunity. However, we note that the likely effect of using the larger area (with its increased heterogeneity) would be a reduced ability to detect any ecological effect (Blakely and Woodward 2000). Third, residual confounding (i.e. area differences that persist after adjustment due to mismeasured or unmeasured factors) at the community level demonstrates that there are still differences between communities that are not being captured by the explanatory variables (Snijders and Bosker 1999), and there is a need to try and account for these between-place variations in occupational activity. One option is to consider other possible sources of contextual variation, including measurement error, or selection effects arising from compositional differences between communities.

We note that if aspects of the environment act as determinants of individual characteristics, adjustment for these characteristics at the individual level may over-adjust the true effects of the context (Diez Roux 2002). This is possible in our models where it is plausible to imagine that, for instance, an individual's income may influence the make-up of the urbanization of the environment, but also that the environment may influence the income potential of the individuals that live within it. Thus, it is unclear whether the individual-level covariate is acting as confounder or an intermediary. Blakely and Woodward suggest that analyses with and without the individual level covariate should be presented to give an upper and lower bound within which the reader may judge the 'true' ecological effect (Blakely and Woodward 2000). We ran models both with education and income included as well as with them excluded and found little effect on either the coefficient for urbanization or the precision of the estimate (data not shown). Thus, though these individual-level predictors do not appear to be operating as confounders of the association between urbanization and occupational activity, we thought it important to include them to account for the compositional effect of the community on occupational activity variance as well as to follow established precedent in the literature.

This study has a number of strengths. First, the use of multilevel modeling helped to separate the community effects from the individual effects on occupational activity with the consideration of both fixed and random effects. Second, our contextual variable, urbanization, was composed of ten different dimensions of infrastructure, economic and demographic items for each community surveyed. This vastly improves our ability to discern influences of urbanization over the traditional urban/rural dichotomy seen in many analyses. Additional analyses were run which substituted the urbanization index with a traditional urban/rural dichotomous measure to see how the results differed. When designated as such, urban residence significantly predicted light occupational activity as expected (data not shown). However, we feel that the assumed homogeneity within the categories "urban" and "rural," as well as the inability to account for change over time, dictate the need for as well as the superiority in using a more nuanced index of urbanization. Third, our use of multiple waves of data enabled us not only to test for time-dependent influences of urbanization on occupational activity, but also to have increased precision when estimating coefficients.

In conclusion, as China continues to urbanize and to shift from an agricultural to a service-based economy, we can expect further declines in work-related activity. Without substitutions of other alternative forms of energy expenditure, we expect increases in the numbers of overweight and obese individuals. Future policy responses should address mechanisms that compensate for increasing sedentariness in occupational life, while remaining aware of features of the environment that facilitate or impede different types of physical activity. China's transition to a more urbanized and technological society is likely to also impact transportation physical activity and leisure time activity. While there has been some research surrounding this in developed countries (Prentice and Jebb 1995; Craig, Brownson et al. 2002; Handy, Boarnet et al. 2002; Sturm 2004; Sturm 2005), additional research is necessary to understand the influence of such changes in developing economies. Policy makers can use findings from studies in the developed world indicating that incorporating "incidental" or "life style" physical activity into the fabric of an individual's life may be the most beneficial way of ensuring an adequate amount of physical activity. As individuals in China live in increasingly technology-dependent environments, findings from this study suggest that those involved in public health promotion efforts, urban planning, and transportation science need to target alternative forms of physical activity in efforts to benefit the health of many millions of humans.

Table 1. Descriptive statistics for baseline (1991) and selected follow-up characteristics of adults in the CHNS sample by gender and type of occupational physical activity

	Men			Women		
	Number	Light or moderate OA[a] (%)	Heavy OA (%)	Number	Light or moderate OA (%)	Heavy OA (%)
Total sample	3034	43.7	56.3	3201	44.2	55.8
Age categories (years)						
18-30	1105	44.0	56.0	1099	48.6	51.4
31-40	910	46.1	53.9	1018	43.8	56.2
41-50	752	39.4	60.6	802	36.3	63.7
51 +	267	46.1	53.9	282	50.7	49.3
Income						
Low	987	20.5	79.5	1006	22.0	78.0
Middle	1059	48.3	51.8	1128	49.2	50.8
High	988	61.9	38.1	1067	59.8	40.2
Education						
None/primary	1096	22.4	77.6	1709	24.6	75.4
Middle school	1258	44.9	55.1	982	58.2	41.8
High school +	680	75.7	24.3	510	82.8	17.2
Urbanization index quartiles						
First (17.2-38.2)	791	8.0	92.0	796	8.2	91.8
Second (38.3-49.2)	854	26.2	73.8	897	23.1	76.9
Third (49.3-65.9)	656	57.0	43.0	709	59.9	46.1
Fourth (66.0-89.4)	733	90.6	9.4	799	95.1	4.9
Urban/rural dichotomy						
Rural	2125	75.1	24.9	2217	76.1	23.9
Urban	909	12.5	87.5	984	10.2	89.8
Occupational activity (follow-up years) [b]						
1993 Light OA	971	81.7	18.3	1001	85.3	14.7
1993 Heavy OA	1274	10.3	89.7	1497	12.8	87.2
1997 Light OA	675	71.8	28.2	698	68.9	31.1
1997 Heavy OA	912	10.2	89.8	921	9.1	90.9

[a] Note: OA = occupational activity
[b] Ns indicate those who had data in both 1991 and 1993 or 1991 and 1997. Totals differ due to loss to follow up

Table 2. Odds ratios and 95% confidence intervals from logistic random intercept multilevel models for men predicting the probability of having light or moderate occupational physical activity

	Model 1[a]	Model 2[a]	Model 3[a]	Model 4[a]
Fixed effects				
Year				
Wave 1991	Ref[b]	Ref	Ref	Ref
Wave 1993	1.34 (1.11, 1.62)**[c]	1.23 (1.01, 1.48)*	1.04 (0.86, 1.26)	1.04 (0.85, 1.26)
Wave 1997	2.58 (2.09, 3.18)***	2.18 (1.76, 2.69)***	1.21 (0.94, 1.55)	1.19 (0.93, 1.54)
Age (in years)				
Age		0.44 (0.31, 0.64)***	0.45 (0.32, 0.65)***	0.10 (0.03, 0.40)**
Age squared		1.02 (1.01, 1.03)***	1.02 (1.01, 1.03)***	1.06 (1.02, 1.10)**
Age cubed		1.00 (1.00, 1.00)**	1.00 (1.00, 1.00)**	1.00 (1.00, 1.00)**
Income				
Low income		Ref	Ref	Ref
Middle income		2.21 (1.76, 2.77)***	2.16 (1.73, 2.70)***	2.18 (1.75, 2.72)***
High income		3.77 (2.93, 4.87)***	3.65 (2.84, 4.68)***	3.69 (2.87, 4.73)***
Education				
None/primary school		Ref	Ref	Ref
Middle school		3.27 (2.53, 4.23)***	3.26 (2.54, 4.19)***	3.28 (2.59, 4.20)***
High school or above		8.69 (6.27, 12.06)***	8.73 (6.36, 11.99)***	8.80 (6.41, 12.07)***
Urbanization index			1.07 (1.05, 1.09)***	1.07 (1.05, 1.09)***
Interaction terms				
Index * age interaction				1.03 (1.00, 1.06)*
Index * age squared				1.00 (1.00, 1.00)*
Index * age cubed				1.00 (1.00, 1.00)*
	Variance (SE)[b]	Variance (SE)	Variance (SE)	Variance (SE)
Random effects	Z	Z	Z	Z
Person level (r_{ij})	3.1372 (0.3789)	2.2867 (0.3134)	2.0949 (0.2897)	2.0721 (0.2873)
	8.280***	7.296***	7.231***	7.212***
Community level (μ_j)	15.5741 (2.1468)	11.1125 (1.5459)	5.1652 (0.9382)	5.0678 (0.9223)
	7.255***	7.188***	5.505***	5.495***

Continued

Table 2 (continued). Odds ratios and 95% confidence intervals from logistic random intercept multilevel models for men predicting the probability of having light or moderate occupational physical activity

	Model 1[a]	Model 2[a]	Model 3[a]	Model 4[a]
Test statistics				
Deviance	6517.9064	6140.4662	6088.6192	6078.8842
Degrees of freedom	5	13	12	16
Likelihood ratio test	--	377.4402 (7)***	51.847 (1)***	9.735 (4)*
Intra-community correlation (ρ)[d]	0.83	0.83	0.71	0.71
% community-level variance explained[e]	--	29% (over model 1)	69% (over model 1) 54% (over model 2)	1.9% (over model 3)

[a] Model 1 controls only for time factors to determine between-community variance in outcome variable; model 2 includes individual-level factors; model 3 includes the community-level predictor, urbanization; model 4 contains relevant interaction terms

[b] Notes: SE = standard error; Ref = referent category

[c] *p<0.05, **p<0.01, ***p<0.001; [d] ICC for level 2 within level 3 (people within communities) = $\mu_j / (\mu_j + r_{ij})$; [e] $(Model_0 – Model_1)/Model_0 * 100\%$

Table 3. Odds ratios and 95% confidence intervals from logistic random intercept multilevel models for women predicting the probability of having light or moderate occupational physical activity

	Model 1[a]	Model 2[a]	Model 3[a]
Fixed effects			
Year			
Wave 1991	Ref[b]	Ref	Ref
Wave 1993	0.89 (0.74, 1.08)	0.88 (0.73, 1.06)	0.79 (0.65, 0.96)*
Wave 1997	3.06 (2.49, 3.75)***[c]	2.92 (2.36, 3.62)***	1.85 (1.43, 2.39)***
Age (in years)			
Age		0.41 (0.29, 0.59)***	0.41 (0.29, 0.59)***
Age squared		1.02 (1.01, 1.03)***	1.02 (1.01, 1.03)***
Age cubed		1.00 (1.00, 1.00)**	1.00 (1.00, 1.00)**
Income			
Low income		Ref	Ref
Middle income		2.08 (1.67, 2.60)***	2.01 (1.62, 2.50)***
High income		2.90 (2.26, 3.71)***	2.78 (2.18, 3.55)***
Education			
None/primary school		Ref	Ref
Middle school		2.46 (1.94, 3.12)***	2.50 (1.98, 3.17)***
High school or above		6.57 (4.64, 9.32)***	6.69 (4.74, 9.45)***
Urbanization index			1.06 (1.04, 1.08)***
Random effects	Variance (SE)[b] Z	Variance (SE) Z	Variance (SE) Z
Person level (r_{ij})	1.8888 (0.2838) 6.655***	1.3194 (0.2339) 5.641***	1.2796 (0.2272) 5.632***
Community level (μ_j)	16.9632 (2.4458) 6.936***	13.3766 (1.9071) 7.014***	7.9937 (1.3632) 5.864***
Test statistics			
Deviance	6147.3198	5694.0796	5660.1464
Degrees of freedom	5	12	13
Likelihood ratio test	--	453.2402(7); p<0.001	33.9332(1); p<0.0001
Intra-community corr (ρ)[d]	0.90	0.91	0.86
% community-level variance explained with additional parameters[e]	--	21.1% (over model 1)	52.9% (over model 1) 40.2% (over model 2)

[a] Model 1 controls only for time factors to determine between-community variance in outcome variable; model 2 includes individual-level factors; model 3 includes the community-level predictor, urbanization

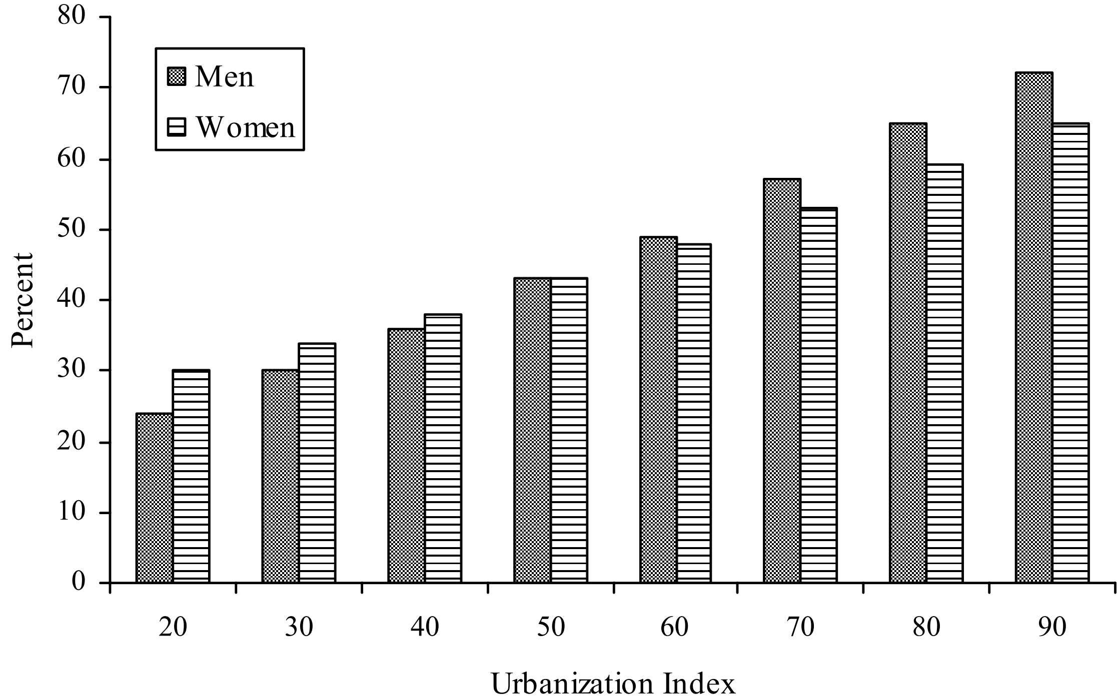
[b] Notes: SE = standard error; Ref = referent category

[c] *p<0.05, **p<0.01, ***p<0.001

[d] ICC for level 2 within level 3 (people within communities) = $\mu_j / (\mu_j + r_{ij})$

[e] $(Model_0 – Model_1)/Model_0 * 100\%$

Figure 1. Predicted proportion of population[a] participating in light or moderate occupational physical activity by urbanization index[b]



[a] Predicted probability calculated using coefficients from Model 3 (from Tables 2 and 3)
[b] Urbanization index ranges from most rural (21.1) to most urban (89.4)

V. Longitudinal relationships between occupational and domestic physical activity patterns and body weight in China

A. Introduction

Globally there are over 1.3 billion overweight adults, and an estimated 300 million obese, with increases partially attributed to population-level reductions in physical activity and increases in sedentary behaviors (WHO/FAO 2003). While there is enormous heterogeneity in the prevalence of obesity throughout the world, and a few lower-income countries such as Mexico and Egypt have rates nearly equal to those seen in the United States, overall obesity prevalence is lower in lower- than in higher-income countries (Popkin and Gordon-Larsen 2004; Mendez, Monteiro et al. 2005). Nonetheless, even in lower-income countries there is evidence that overweight and obesity are becoming matters of public health concern (Popkin and Gordon-Larsen 2004; Mendez, Monteiro et al. 2005; Popkin in press). This is certainly true in China, where there has been a recent and dramatic rise in the number of overweight adults in the recent past (Bell, Ge et al. 2001; Du, Lu et al. 2002). Further, rapid economic and social change has led to increased use of time- and labor-saving technologies, potentially reducing energy expenditure in both the home and occupational sectors (Popkin 2003). In fact, some economists have argued that technological change is responsible for the obesity epidemic largely because of its effect of reducing energy expenditure in the workplace, mainly related to advancements in workplace technology (Lakdawalla and Philipson 2002; Philipson and Posner 2003).

The majority of research examining the association between physical activity and overweight has focused on the analysis of leisure time physical activity, excluding other sources of energy expenditure. However, evidence from studies that have examined physical activity in the domestic and occupational spheres has shown these sources to be important (Weller and Corey 1998; Evenson, Rosamond et al. 2003). In China occupational activity has been shown to be the key modifiable determinant of weight gain (Bell, Ge et al. 2001). Further, it is possible that in lower-income countries, such as China, with reduced access to technology both at home and in the marketplace, occupational and domestic physical activity may contribute a substantial proportion of an individual's total energy expenditure, and thus may have a considerable impact on weight. However, there has been limited population-based, longitudinal research on weight and activity trends. This study attempts to fill these gaps by studying the longitudinal association of weight to energy expended in occupational and domestic physical activity in a socioeconomically and demographically diverse sample of Chinese adults.

B. Methods

1. Study population

Data were derived from the China Health and Nutrition Survey (CHNS) an ongoing, longitudinal survey designed to investigate how the social and economic transformation of the Chinese society is affecting the health and nutritional status of its population. The initial survey was conducted in 1989 in eight provinces (Shangdong, Jiangsu, Hunan, Hubei, Henan, Guizhou, Guangxi, and Liaoning); follow-up surveys were conducted in 1991, 1993, 1997, and 2000; although the Heilongjiang province replaced Liaoning in 1997, they both returned in 2000. While the survey is not nationally representative, the provinces do vary substantially in geography, stage of economic development, and health status. Counties within the province were stratified by income (low, middle, high) and a weighted sampling scheme was used to randomly select four counties in each province (1 high-, 2 middle-, and 1 low-income). In addition, the provincial capital city along with a lower-income city was selected. Within each county/city, neighborhoods were randomly selected from urban and suburban areas, townships, and villages. Twenty randomly selected households were surveyed within each neighborhood.

For these analyses we used all available data from adults aged 18-55 surveyed in 1991, 1993, 1997, and 2000 (N=4697 women, N=4708 men). Individuals missing data for any variable included in the final models were excluded as were pregnant women and all data from the 1989 survey due to differences in the questionnaire regarding one of our primary exposure variables.

2. Study variables

a. Anthropometrics and overweight status

Anthropometric data were collected by trained health workers during a comprehensive physical exam. Height was measured without shoes to the nearest 0.2 cm using a portable stadiometer; weight was measured without shoes and in light clothing to the nearest 0.1 kg on a calibrated beam scale. Body Mass Index (BMI; weight in kilograms/height meters^2) was used continuously and also to define overweight and obesity relative to the World Health Organization and the International Obesity Task Force BMI cutpoints of 25 and 30, respectively.

b. Occupational activity

Occupational activity data were derived from multiple questions in reference to wage work including occupations both outside and inside the home. By including work that is distinct from the wage sector we were able to get a more comprehensive measure of overall energy expenditure in work. Categories included working on a farm, working in a vegetable garden or orchard, raising livestock or poultry, work fishing, working in a home business, and work from up to two "traditional" market-based jobs (e.g. working in an office, as a policeman, in construction, etc.). For each component, respondents were asked the average number of hours per week in the last year spent in the specified activity.

To create a measure of energy expenditure, we multiplied the time spent in each occupational activity category by a specific metabolic equivalent (MET) intensity value, for a final value in units of MET-hours per week. One MET is considered a resting metabolic rate obtained during quiet sitting, while MET values <3 are considered light, those between 3 and 6 are considered moderate, and those ≥6 are considered vigorous (Pate, Pratt et al. 1995). We assigned MET values to specific occupations using the self-reported measure of work intensity, including standing, sitting, lifting, etc., available in the CHNS. Respondents were categorized as having light, moderate, or heavy occupational activity. Next, for each specific occupation, we assigned MET values of 2, 4, and 6 to occupations reported as light, moderate, and heavy, respectively, based on how the majority of respondents were classified with respect to their self-reported occupational activity. Farming, fishing, or working in a garden/orchard were overwhelmingly reported as being high intensity occupations; those working in livestock were more varied, but the majority still reported high occupational activity. Thus, these activities were given a MET value of 6 (heavy). MET values of 2 (light) were given to those working in a home business, working as a senior or junior professional, working as an administrator, executive, manager, or office staff, and working as an army officer or police officer; MET values of 4 (moderate) were given to those working as a skilled worker (foreman, group leader, craftsman), as a non-skilled worker (ordinary laborer, logger), and as a driver, homemaker, or student. Individual MET-hours per week values were then summed to obtain a measure of overall occupational activity energy expenditure. We categorized total occupational activity based on a 40-hour work week at <3 (low), 3-6 (medium), and ≥6 (high) METs (i.e. <120, 120-240, and ≥240 MET-hours/week).

c. Domestic activity

For an overall measure of domestic physical activity we used four different activities that were available in all four survey years: time spent preparing food, buying food, doing laundry, and time spent in childcare. Unfortunately, we were unable to use other measures of domestic activities such as cleaning house and time spent caring for elderly parents because they were not obtained in all survey years. In bivariate analyses, cleaning house was inversely associated with overweight status for men and women, but time spent caring for elderly parents was not. Exclusion of these activities will lead to an underestimation of overall energy expenditure spent in domestic activity, and a possible attenuation in the relationship between domestic activity and overweight. All activities were reported in average hours per week spent in the last year.

To create a measure of energy expenditure for domestic activities, we again multiplied the time spent in each domestic activity category by a specific MET intensity value for a final value in units of MET-hours per week. For specific MET intensity values we utilized the Compendium of Physical Activities (Ainsworth, Haskell et al. 2000), assigning a MET value of 2.25 to preparing food, 2.3 to buying food, 2.15 to doing laundry, and 2.75 to childcare. Individual MET-hours per week values were then summed to obtain a measure of overall domestic activity energy expenditure. Categories for domestic activity for women were created based on the observed relationship with overweight status seen in the data at baseline: 0, >0 to <50, 50-200, and ≥200 MET-hours/week. For men, who spent far less time than women in domestic activity, the variable was dichotomized as any versus none. On average, the majority of domestic time was spent in childcare, and it is possible that these hours were overestimated due to multi-tasking. For this reason we also ran analyses with this activity separated out from the other three. Categories for men were still dichotomized as any versus none, while categories for women were, for childcare: 0, >0 to <200, and ≥200 MET-hours/week, and for the remaining three domestic activities: 0, >0 to <40, 40-80, and ≥80 MET-hours/week.

3. Statistical analysis

The goal of this analysis was to examine the total within- and between-person effects of different activity pattern measures on weight. All analyses were stratified by gender to account for the different occupational and domestic environments for men and women in China. Age and age-squared were used to model the observed curvilinear relationship between age and weight in the data and were included in models along with total energy intake (in kilocalories) and height (in meters) as continuous variables. Entered into the model as indicator variables were deflated household income per capita divided into tertiles, comparing low income to middle or high income categories; education, which was categorized as having a primary school education or less, a middle school education, a high school education, or a college education; urban (versus rural) residence; and indicator variables for the survey years (versus baseline 1991). Potential interactions between urban residence and activity as well as survey year and activity were examined by entering cross-product terms into the models, but we observed no meaningful effect modification so interaction terms were not retained in the final models.

We used longitudinal linear random effects models to investigate the relationship of occupational and domestic activity to weight. In our first model occupational activity was included with total domestic activity; model 2 replicated model 1 with the exception that the childcare component of domestic activity was separated out from the other three forms of domestic activity. We next ran additional longitudinal models to estimate the effect that owning various labor-saving household devices had on weight. Further analyses were run using BMI as the dependent variable, with results that mirrored those using weight; we chose to show results with weight as the dependent variable due to increased interpretability of coefficients. We used random effects models in our analyses because they adjust for the correlation between repeated observations taken in the same subject, have the advantage of handling longitudinal data on subjects with varying number and unequally spaced observations, thereby allowing for inclusion of the maximum number of datapoints, and use both within- and between-individual change to assess the association. We also ran similarly specified fixed effects models, which use only the within-individual change to estimate the effect on weight. Fixed-effects models are rigidly-specified and rarely used, and we decided upon the random effects model as our final model because our main interest was in the total effect of activity, not just the within-individual effect. Inclusion of time (survey year) into the models allows us not only to estimate the effect of time on the outcome, but also serves to control to some extent for unobserved, time-varying variables. Data management was handled in SAS version 8.2 (SAS Institute Inc., Cary, NC) and statistical procedures were implemented in Stata version 9.1 (Stata Corporation, College Station, TX).

C. Results

At baseline (1991), men and women who had less occupational activity had higher overweight prevalence (Table 4). Similarly, overweight prevalence was higher in urban residents, and individuals of middle or upper income. Among men only, overweight prevalence was significantly higher in those with some college or technical education.

1. Time trends of weight status and energy expenditure

Figure 2 shows trends in the prevalence of overweight and obesity over the 9-year study period. Between 1991 and 2000 overweight increased in men from 7.9% to 19.4%, a 146% increase; over the same time period, overweight increased in women from 12.2% to 20.7%, a 70% increase. While the obese represent a small proportion of this sample of Chinese adults, obesity increased 233% and 108% in the 9-year period for men and women, respectively. The mean weight change over the 9-year period was 3.9 ± 6.5 kg for men and 3.6 ± 5.9 kg for women. The highest rate of weight gain occurred between 1997 and 2000 for men (1.6 ± 5.4 kg), and between 1993 and 1997 for women (1.5 ± 4.9 kg).

Figure 3 shows trends in the average energy expenditure for occupational and domestic activity by gender over the 9-year study period. Energy expenditure from occupational sources declined 22% and 24% in men and women, respectively, while that from domestic sources declined 57% and 51% in men and women, respectively. At baseline, women worked only marginally more MET-hours per week than men in occupational activities, but worked over 4 times as many MET-hours per week as men in domestic tasks.

Figure 4 shows trends in the acquisition of labor-saving household goods over the 9-year study period. Between 1991 and 2000, ownership of washing machines rose by 40%, and there was more than a doubling in the ownership of refrigerators. Cooking appliances such as electric pots and pressure cookers rose by 150% and 70%, respectively, and there was an enormous 28-fold increase in the ownership of microwave ovens. Overall, ownership of appliances was higher in urban than in rural areas; however, the rate of acquisition between 1991 and 2000 in the rural areas exceeded that in the urban areas (data not shown). Figure 5 shows differences in the proportion of the adult population working in common occupations in 1991 and in 2000. Farming remains the most frequently reported occupation; however, both farming and occupational laborer have decreased, while sedentary occupations have risen from 22% to 32% of the workforce.

2. Determinants of body weight in men and women

Longitudinal multivariate models correcting for within-subject correlation were estimated to investigate the net effect of occupational and domestic activity on weight in men and women. In further analyses, we ran longitudinal multivariate models to estimate the net effect of owning various labor-saving household devices on weight.

Results of regressing weight on occupational and domestic activity are summarized in

Table 5. Results from Model 1 show that for men, the net effect of increasing from low occupational energy expenditure (<120 MET-hours/week) to medium occupational energy expenditure (120-240 MET-hours/week) was a significant reduction in weight of, on average, 0.3 kg (ß coefficient –0.2857); increasing from low to high occupational energy expenditure (≥240 MET-hours/week) had the net effect of significantly reducing weight, on average 0.5 kg (ß coefficient –0.4588). Similarly for women, increasing from low to medium or low to high occupational energy expenditure had the net effect of significantly reducing weight 0.3 and 0.4 kg, respectively (ß coefficients –0.2879 and –0.3585).

Results from total domestic activity (Model 1) indicate that, for men, the net effect of any domestic activity resulted in a significant reduction in weight of approximately 0.5 kg. When childcare was separated from the other three domestic tasks (Model 2), both had an inverse association with weight; however, the effect of childcare on weight was slightly less than that from the other three tasks, and was only marginally statistically significant (p=0.051).

For women, although coefficients from total domestic activity (Model 1) were in the expected inverse direction, they failed to reach statistical significance, and do not indicate a dose-response relationship with increasing levels of energy expenditure. Similarly, when childcare was separated from the other types of domestic activity (Model 2), the coefficients for both sets of activity were in the expected inverse direction but again failed to reach statistical significance. While there was the suggestion of an inverse dose-response relationship with increasing levels of energy expenditure in childcare, this was not seen with the other types of activity.

Using the coefficients from Model 1 and the activity distribution in 1991, we calculated the expected average weight for men and women in 2000 given baseline physical activity levels, assuming all other factors remained the same. We found that if men and women had remained at their 1991 physical activity levels, they would, on average, weigh 4.6 kg and 4.0 kg less, respectively, in 2000 than they, on average, do.

Table 6 presents results from analyses in which we investigated the net effect of owning various labor-saving domestic appliances (shown in Figure 4 to have increased dramatically in the study period) on weight in men and women. Results indicate that, in men, the net effect of ownership of any one of the appliances resulted in a significant increase in weight, most dramatically for refrigerators (ß coefficient 1.3729). In women, the net effect of owning a washing machine, refrigerator, or an electric pot resulted in a significant increase in weight, while owning a microwave oven or a pressure cooker did not (although pressure cooker ownership was marginally significant, p value=0.053).

D. Discussion

In this diverse sample of adult Chinese men and women, the prevalence of overweight nearly doubled in women and more than doubled in men between 1991 and 2000, a troubling trend for the approximately 700 million Chinese adults. Further, we have demonstrated how energy expenditure from occupational and domestic sources has decreased over the study period. The primary results of this longitudinal study show that the net effect of increasing occupational physical activity resulted in overall lower body weight for both men and women, and increasing domestic physical activity resulted in overall lower body weight in men. We have also shown how the net effect of ownership of various labor-saving household devices resulted in overall increases in weight for both men and women.

While it is likely that some declines in occupational activity levels are occurring within job categories due to increasing technology and automation (Hill and Melanson 1999; French, Story et al. 2001), this study did not attempt to capture within-job activity changes. In our study, declines in occupational activity were due to (1) decreases in the overall time spent (from a mean of 53.6 to 45.2 hours/week for men, and from 52.3 to 43.5 hours/week for women) and (2) shifts over time in the types of jobs held. Between 1991 and 2000 the biggest occupational shifts included a decline in farming and an increase in home businesses (which represents a relatively small proportion of reported occupations). Over time, both men and women transitioned into more sedentary occupations such as professional or technical workers, or drivers and fewer worked in more physically exerting jobs such as craftsman, laborer, or logger.

Results from studies examining the relationship between occupational activity and obesity are mixed. While some inverse associations have been reported between occupational activity and obesity and its associated sequelae (King, Fitzhugh et al. 2001; Barengo, Hu et al. 2004; Mummery, Schofield et al. 2005), others have found no association (Ball, Owen et al. 2001; Gutierrez-Fisac, Guallar-Castillon et al. 2002). The majority of this work has been done in higher-income countries where leisure time physical activity is far more prevalent, and studies have shown the interaction of leisure time and occupational activity to be quite complex (Burton and Turrell 2000; Salmon, Owen et al. 2000; King, Fitzhugh et al. 2001; Evenson, Rosamond et al. 2003). In China, however, adults acquire the majority of their daily physical activity in their working lives and leisure time physical activity is still relatively uncommon; thus highlighting the importance in considering occupation when assessing overall energy expenditure. For instance, in an earlier study using this cohort, Bell *et al* found that occupational activity was the key modifiable determinant of weight gain (Bell, Ge et al. 2001). Further studies in Chinese populations have shown occupational shifts from more strenuous to less strenuous jobs to be associated with adverse changes in cardiovascular risk factors (Xu, Niu et al. 1997; Zhou, Li et al. 2003), and energy expenditure as measured by doubly-labeled water in urban Chinese adults was found to be inversely associated with body fatness (Yao, McCrory et al. 2003).

We have also illustrated the decline in physical activity due to domestic duties in this population. As with occupational activity, we did not capture the change in strenuousness of a task over time; rather, we are captured a lessening of the overall time spent in domestic activity. For example, between 1991 and 2000, total hours per week spent by men in domestic tasks declined from a mean of 7.2 to 3.4, and for women hours per week declined from 27.2 to 15.6. In developing countries such as China, it is possible that domestic activity substantially contributes to overall physical activity due to lower household mechanization, but urbanization has promoted the acquisition of labor-saving devices in the home which have been shown to decrease energy expenditure (Lanningham-Foster, Nysse et al. 2003). There have been notable increases in urbanization in China over these years (Popkin 1998; Mendez, Monteiro et al. 2005; Mendez and Popkin under review), which has increased access to and availability of these types of appliances.

We hypothesized that the decline in domestic activity was partially attributable to the increasing availability and purchase of household assets not easily obtained in the past, including time-saving household goods. We have demonstrated that ownership of a number of labor-saving household devices dramatically increased over the study period. Further, ownership of such devices was associated with increased weight in both men and women, after controlling for socioeconomic factors and urban residence. Obviously, ownership of these devices does not, *per se*, make one overweight, rather it is through the effect that they have on the reduction of time spent in domestic tasks. On the other hand, these measures might really represent proxies for long-term overall wealth and may not affect time utilization patterns. One interesting finding is that ownership of a microwave oven was significantly associated with reduced weight in men only. It is possible that single men, or men who live apart from their families, own more microwaves than households where a woman is responsible for the majority of the food preparation. In fact we found that men were significantly more likely to own microwaves then women, and that men working sedentary jobs were more than six times as likely (OR=6.46, $p<0.001$) to own microwaves than those with heavy intensity jobs, even after controlling for socioeconomic factors and urban residence. Again, it is important to realize that controlling for income as we have done is not equal to controlling for wealth. Thus these effects may suffer to some degree from residual confounding.

Recent research has highlighted the importance of including domestic activity in assessing total energy expenditure, primarily in women. In a prospective study examining the relationship between physical activity and mortality in women, Weller *et al* concluded that the inverse relations were due mainly to the contribution of domestic physical activity (Weller and Corey 1998), while Phongsavan *et al* concluded that inclusion of domestic sources of activity was important in women attaining sufficient levels of activity (Phongsavan, Merom et al. 2004). In a cross-sectional study, however, while Lawlor *et al* agreed that domestic activity was important in assessing sufficient levels of activity, it had no independent effect on levels of overweight in elderly white women (Lawlor, Taylor et al.

2002).

In this study we did not examine whether individuals reached recommended levels of physical activity; rather, we focused on the effect of total activity on weight. Our results suggest an inverse dose-response relationship of occupational activity with weight in men and women; while in men we found a statistically significant inverse relationship between any domestic activity and weight. Differences between men and women in domestic activity could be due to the vigorousness with which tasks were completed, or that men tended to undertake the more labor-intensive portions within any household task. In fact, other research on rural Chinese men who undertake domestic work indicates they are generally middle-aged and married with no other women in the family to help with domestic duties (Jacka 1997). If true, it may be incumbent upon these men to contribute in ways that are more vigorous and labor-intensive. In our sample, men who did domestic tasks were older, more rural, and had higher incomes and more education than those who did not. However, we did not have data on extended family living arrangements to determine whether there were other women in the household.

A major strength of this study is that we were able to include multiple sources of occupational activity. Because many in China hold multiple jobs, whether they take place at home or away from home, the inclusion of this activity allows a more complete assessment of total work. This may be especially important for women in developing countries, because of the multiple tasks that women do, both at home in the domestic and occupational spheres, and away from home in the traditional work sphere (McGuire and Popkin 1989; McGuire and Popkin 1990; Donahoe 1999; Short, Chen et al. 2002). This importance is borne out when we examine the proportion of women who report having multiple work burdens: over

1/3 of women overall and over 40% of women residing in rural areas report doing three or more types of occupational work, in addition to their domestic responsibilities. A further strength of this study is our ability to assess and quantify domestic activity. This source of activity, while researchers have acknowledged its importance, has been understudied, and appears to be an important source of energy expenditure for this population.

A few limitations of this work warrant addressing. First, activity data for both occupational and domestic sources rely on self-report, which can lead to by recall bias. Studies have shown that overweight individuals tend to over-report their physical activity (Lichtman, Pisarska et al. 1992; Buchowski, Townsend et al. 1999); however, the majority of this work has been done in populations from higher-income countries and not in lower-income developing countries where the stigma with being overweight is much smaller. Nonetheless, if this were the case in these data, over-reporting of activity data would only serve to attenuate the estimates by misclassifying overweight individuals as being more active than they truly are. Second, it is possible that overweight individuals may self-select into specific, potentially more sedentary, job types, although this may be slightly less of a problem in China because jobs have tended to be more circumstantial with less mobility and job choice. Third, the use of job description to assess energy expenditure has been criticized because it can be subject to mis-measurement due to within-job variability and job intensity misclassification (Evenson, Rosamond et al. 2003; Vaz and Bharathi 2004). Yet it has been shown that methods similar to ours of assessing occupational activity by way of hours worked per week and the average MET intensities of job activities provide good validity (Ainsworth, Jacobs et al. 1993). Finally, using METs to quantify energy expenditure does not take into account individual differences such as age, sex, and geographic and environmental conditions that may alter the energy cost of movement (Ainsworth, Haskell et al. 2000). However, despite its limitations, the MET approach remains the best available way to systematically apply energy cost estimates in self-report measures (Matthews 2002).

The trend toward increasing overweight and obesity continues unabated in this sample of Chinese adult men and women, and, as we have seen in many other countries throughout all regions of the world, few of the individuals who gain weight lose that weight. Further, with ever increasing urbanization and technological advances as China continues in its social and economic transformation, increasing sedentariness in both occupational and domestic work appears to be inevitable (Monda, Gordon-Larsen et al. revise and resubmit status). It is unrealistic to expect that this trend will lessen in upcoming years for upcoming generations, and adults will continue to transition to more sedentary jobs, and jobs that were once more labor-intensive will become more sedentary. If we look to developed countries as an example, we might expect that as young people enter the work force their first jobs will more likely be sedentary, and their home lives will similarly be less active and more efficient, freeing up more leisure time. From a public health standpoint, it seems important that as this transition continues, the populace should be encouraged and advised to use the advent of more leisure time to engage in active pursuits in attempts to prevent and control a widespread obesity epidemic.

Table 4. Baseline (1991) characteristics of men and women stratified by overweight status

	Men		Women	
	Not-overweight (N=2502)	Overweight (N=246)	Not-overweight (N=2624)	Overweight (N=392)
Age (years)	35.3 ± 9.8	39.2 ± 8.9**	34.6 ± 9.5	38.5 ± 8.3**
Urban residence (%)	27.9	51.6**	26.2	35.2**
Income Tertiles (%)				
Low	32.7	12.6[a]	32.7	21.4[a]
Middle	34.4	42.3[b]	34.4	38.3[b]
High	32.9	45.1[b]	32.9	40.3[b]
Education (%)				
None/primary	36.5	28.9[a]	53.3	53.6
Middle school	42.0	40.7[a]	31.1	29.9
High school	14.9	17.9	11.5	11.0
College/technical	6.7	12.6[b]	4.1	5.6
Total energy intake (kcal)	2893.8 ± 681.6	2879.2 ± 663.9	2537.7 ± 639.5	2544.3 ± 636.2
Occupational activity (mean MET-hrs/wk)	234.3 ± 139.7	180.1 ± 103.0**	254.4 ± 161.0	214.7 ± 146.9**
Domestic activity (mean MET-hrs/wk)	18.0 ± 36.4	17.3 ± 25.8	64.9 ± 64.2	63.7 ± 53.9

Continuous variables are mean ± standard deviation, categorical variables are proportions
*p<0.01; **p<0.001
[a,b] Within income and education categories, proportions that differ from one another by ANOVA at p≤0.01 noted with different letters

Table 5. Results from longitudinal models of occupational and domestic physical activity on weight in men and women, 1991-2000[a]

	Men		Women	
	Coefficient	95% CI[b]	Coefficient	95% CI
Model 1				
Occupational activity				
<120 MET-hrs/wk	Ref[b]		Ref	
120 to <240 MET-hrs/wk	-0.2857*	-0.5578, -0.0137	-0.2879*	-0.5245, -0.0513
≥240 MET-hrs/wk	-0.4588**	-0.7638, -0.1537	-0.3585**	-0.6196, -0.0975
Total domestic activity				
Any MET-hrs/wk[d]	-0.4511***	-0.6646, -0.2375	-	-
0 MET-hrs/wk	-	-	Ref	
>0 to <50 MET-hrs/wk	-	-	-0.2235	-0.6225, 0.1756
50 to <200 Met-hrs/wk	-	-	-0.1740	-0.5956, 0.2476
≥200 MET-hrs/wk	-	-	-0.1587	-0.8240, 0.5066
Model 2[c]				
Domestic activity: Buying food, preparing food, laundry				
Any MET-hrs/wk[d]	-0.3993***	-0.6162, -0.1824	-	-
0 MET-hrs/wk	-	-	Ref	
>0 to <40 MET-hrs/wk	-	-	-0.2374	-0.6204, 0.1455
≥40 MET-hrs/wk	-	-	-0.1056	-0.5074, 0.2963
Domestic activity: Childcare				
Any MET-hrs/wk[d]	-0.3397	-0.6815, 0.0021	-	-
0 MET-hrs/wk	-	-	Ref	
>0 to <200 MET-hrs/wk	-	-	-0.1764	-0.4103, 0.0576
≥200 MET-hrs/wk	-	-	-0.4389	-1.3094, 0.4316

[a]Longitudinal linear random effects models controlled for height, urban residence, age, income, education, total energy intake, and survey year.
[b]CI=confidence interval; Ref=referent category; *p<0.05; **p<0.01; ***p<0.001
[c]Model 2 also includes occupational activity as specified in Model 1, results did not substantially differ so are not shown above.
[d]None is referent

Table 6. Results from longitudinal models of ownership of labor-saving household devices on weight in men and women, 1991-2000[a]

	Men		Women	
	Coefficient	95% CI[b]	Coefficient	95% CI
Washing machine	1.1572**	0.8714, 1.4430	0.9599**	0.7055, 1.2144
Refrigerator	1.3729**	1.0539, 1.6919	1.2900**	1.0086, 1.5713
Microwave	1.2531**	0.5283, 1.9779	0.3589	-0.2664, 0.9842
Electric pot	0.8662**	0.6000, 1.1325	0.4471**	0.2113, 0.6829
Pressure cooker	0.3020*	0.0089, 0.5951	0.2570	-0.0033, 0.5174

[a]Longitudinal linear random effects models controlled for urban residence, age, income, education, total energy intake, and survey year
[b]CI=confidence interval; *p<0.05; **p≤0.001

Figure 2. Trends in the prevalence of overweight (BMI≥25-<30) and obesity (BMI≥30) in adult men and women, CHNS 1991 to 2000

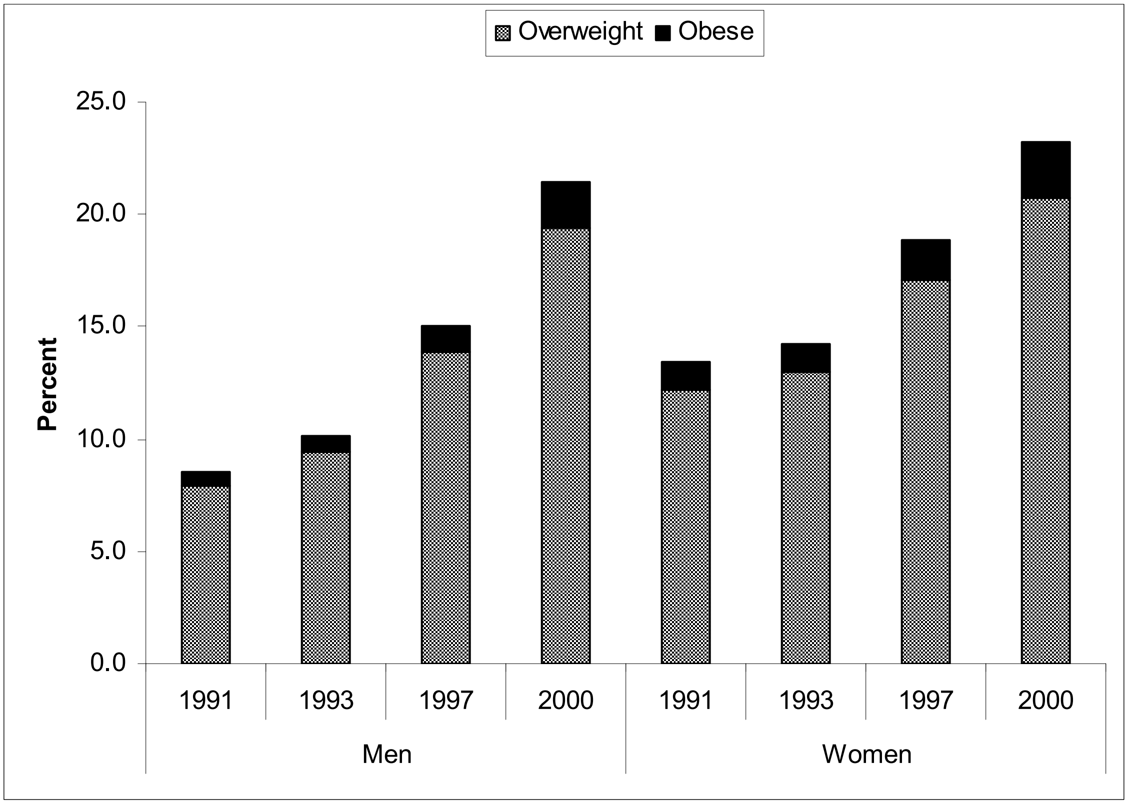


Figure 3. Trends in average energy expenditure in MET-hours/week from occupational and domestic physical activity for adult men and women, CHNS 1991-2000

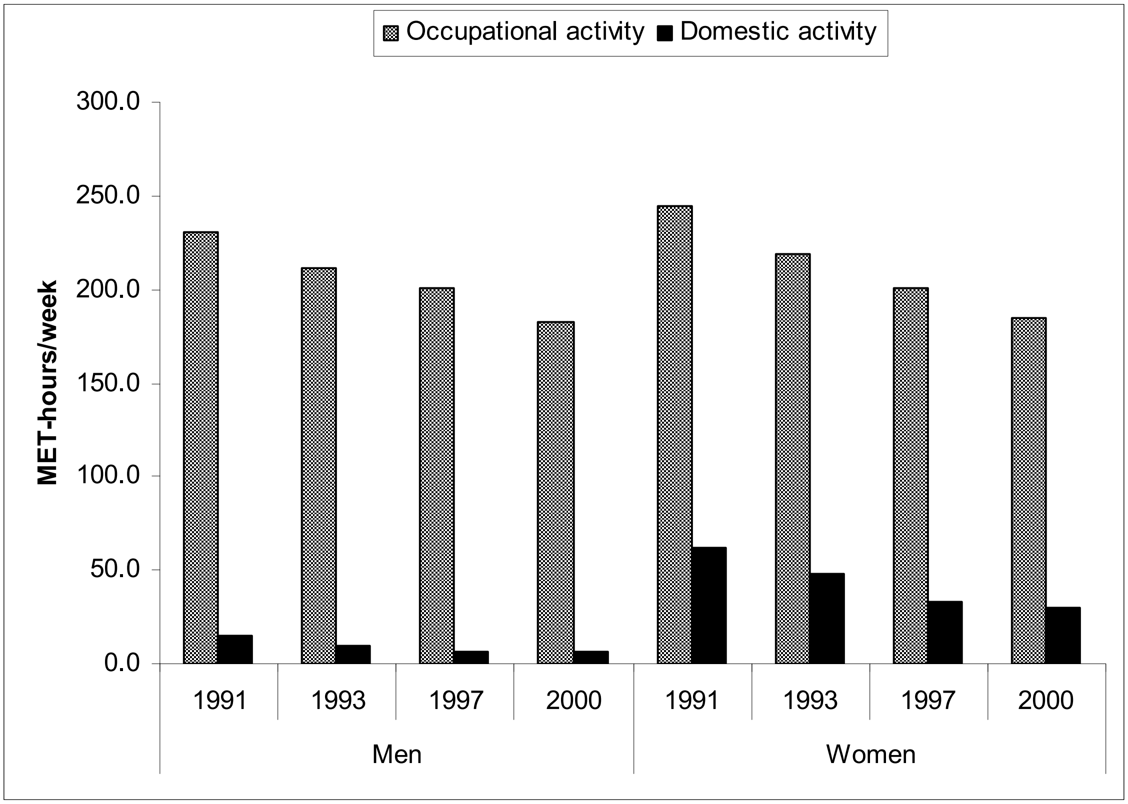


Figure 4. Trends in the acquisition of labor-saving household goods between 1991 and 2000 in the CHNS

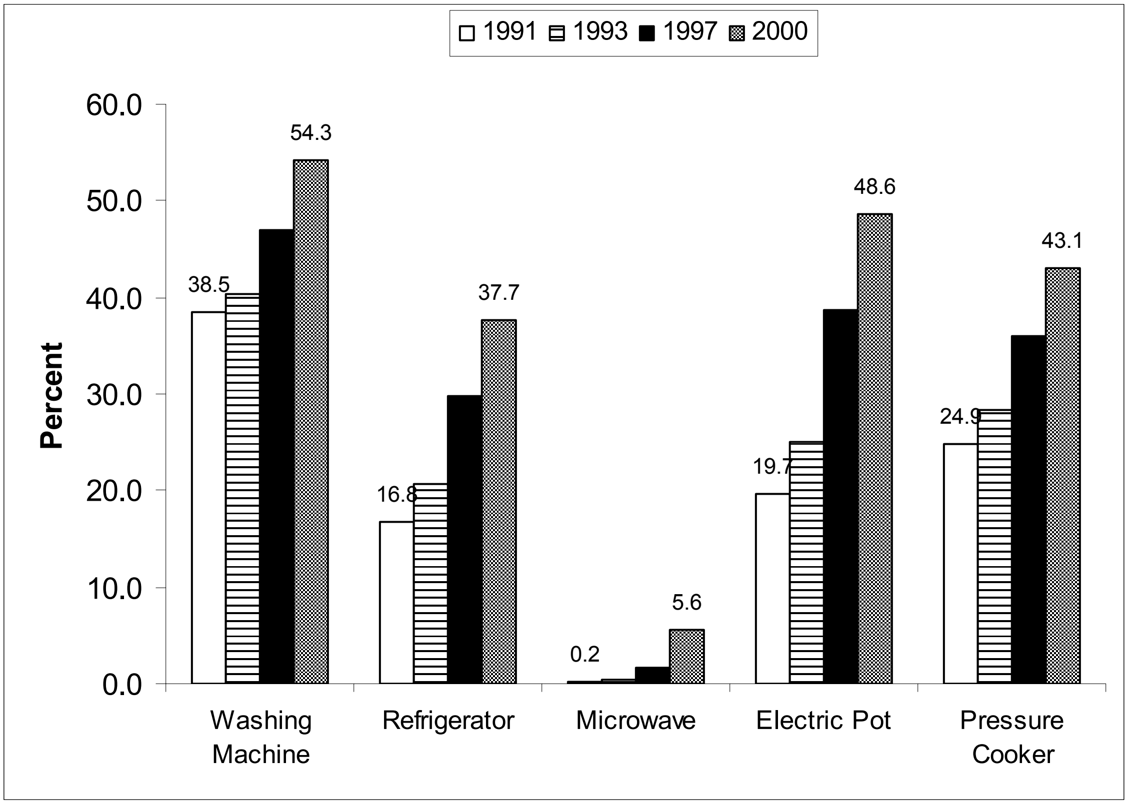
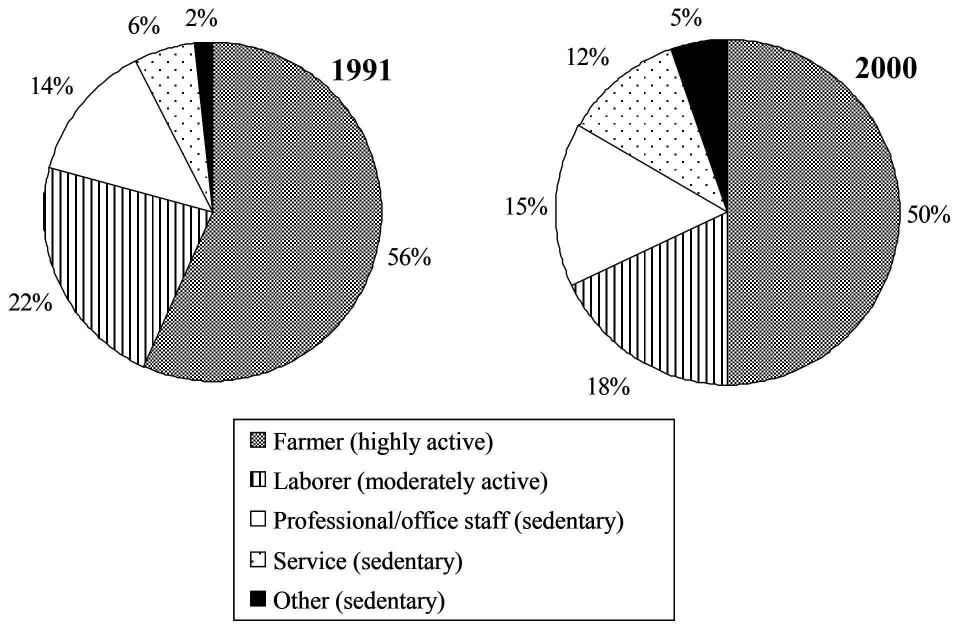


Figure 5. Trends in the proportion of the adult population working in common occupations in 1991 and 2000 in the CHNS



VI. Assessing the cross-sectional and longitudinal effect of multiple domains of physical activity in China: Do they matter for weight status?

A. Introduction

The rising prevalence of overweight and obesity throughout the world has prompted the recognition of a "global epidemic" (WHO 1998), with increases partially attributed to population-level reductions in physical activity and increases in inactivity. The relationship of physical activity to weight status has been fairly well documented in cross-sectional studies (DiPietro 1995), but longitudinal results are often mixed (Fogelholm and Kukkonen-Harjula 2000; Wareham, van Sluijs et al. 2005). In China we have a unique opportunity to study this relationship as the society undergoes rapid transformation and urbanization: not only have there been dramatic rises in overweight prevalence in the adult population, but there have been concomitant increases in car ownership, in labor-saving household devices, in the mechanization of the workplace, as well as decreases in the proportion of the workforce employed in more physically-demanding occupations such as farming(Bell, Ge et al. 2001; Popkin 2001; Bell, Ge et al. 2002; Du, Lu et al. 2002).

Overweight and obesity are emerging as a significant public health problem in China, as well as throughout Asia (Popkin, Horton et al. 2001; Florentino 2002; Adair 2004). The adverse effects of overweight and obesity on health, longevity, and quality of life are well recognized, among them increased risk of morbidity and mortality from chronic conditions such as type 2 diabetes mellitus, coronary heart disease, and some cancers (Must, Spadano et al. 1999; Patterson, Frank et al. 2004). The numerous health benefits from adopting regular physical activity on a long-term basis, independent of body weight changes, are also well documented, including a reduced risk of type 2 diabetes mellitus, osteoporosis, and reduced symptoms of anxiety and depression (Schmitz, Jacobs et al. 2000; Li, Rana et al. 2006).

Physical activity takes place in a variety of different domains such as the occupational and domestic sectors, as well as in transportation, and sports and exercise during leisure time. Researchers have suggested that each domain should be assessed separately to examine effects of specific activities and to have a more valid understanding of activity than is possible with an overall assessment (Wareham, van Sluijs et al. 2005). Much of the physical activity research from developed countries focuses on leisure activity, excluding other sources. However, in China, very few individuals participate in active pursuits during their leisure time, and assessment of activity from other domains may prove to be important. In fact, a number of studies have concluded that the contributions of domestic and work-related physical activity are potentially relevant to determining physical activity-weight associations (Salmon, Owen et al. 2000; Lawlor, Taylor et al. 2002; Evenson, Rosamond et al. 2003; Phongsavan, Merom et al. 2004).

In earlier analyses we showed that both occupational and domestic physical activity were important predictors of overweight status in Chinese men and women. Our goal in these analyses was to increase the scope of our earlier work by including physical activity from transportation and leisure sources as well, and to investigate the cross-sectional and longitudinal associations between physical activity and weight status. We hypothesized that in cross-sectional analyses higher levels of physical activity, regardless of domain, would be associated with reduced likelihood of overweight; further, that changes in physical activity would partially explain weight changes over the three-year period.

B. Methods

1. Study population

Data were derived from the China Health and Nutrition Survey (CHNS), an ongoing, longitudinal survey designed to investigate, among other things, how the social and economic transformation of the Chinese society is affecting the health and nutritional status of its population. The initial survey was conducted in 1989 in eight provinces (Shangdong, Jiangsu, Hunan, Hubei, Henan, Guizhou, Guangxi, and Liaoning); follow-up surveys were conducted in 1991, 1993, 1997, and 2000; although the Heilongjiang province replaced Liaoning in 1997, they both returned in 2000. While the survey is not nationally representative, the provinces do vary substantially in geography, stage of economic development, and health status. Counties within the province were stratified by income (low, middle, high) and a weighted sampling scheme was used to randomly select four counties in each province (1 high-, 2 middle-, and 1 low-income). In addition, the provincial capital city along with a lower-income city was selected. Within each county/city, neighborhoods were randomly selected from urban and suburban areas, townships, and villages. Twenty randomly selected households were surveyed within each neighborhood.

For cross-sectional analyses we used data from adults aged 18-55 surveyed in 1997 or 2000 (1997: N=2457 men and 2492 women; 2000: N=2110 men and 2167 women). Longitudinal analyses were limited to those who were aged 18-55 and provided data in both survey years (N=1144 men and 1235 women).

2. Study variables

a. Anthropometrics and overweight status

Anthropometric data were collected by trained health workers during a comprehensive physical exam. Height was measured without shoes to the nearest 0.2 cm using a portable stadiometer; weight was measured without shoes and in light clothing to the nearest 0.1 kg on a calibrated beam scale. BMI was calculated as weight in kilograms divided by the square of height in meters. The BMI cut-off point of 25 was used to define overweight, as recommended by the World Health Organization and the International Obesity Task Force. Further, individuals were categorized as weight gainers if they gained ≥3% body weight, weight losers if they lost ≥3% body weight, and weight maintainers if they gained or lost within 3% of body weight (Stevens, Truesdale et al. 2005).

b. Occupational activity

Occupational activity data were derived from multiple questions in reference to wage work including occupations both outside and inside the home. By including work that is distinct from the traditional market-based job sector (e.g. working in an office, as a policeman, in construction, etc.) we were able to get a comprehensive assessment of overall energy expenditure in work. Categories included working on a farm, working in a vegetable garden or orchard, raising livestock or poultry, work fishing, working in a home business, and work from up to two market-based jobs. For each component, respondents were asked the average number of hours per week in the last year spent in the specified occupation.

To create a measure of energy expenditure, we multiplied the time spent in each occupational activity category by a specific metabolic equivalent (MET) intensity value, for a final value in units of MET-hours per week. One MET is considered a resting metabolic rate obtained during quiet sitting, while MET values <3 are considered light, those between 3 and 6 are considered moderate, and those ≥6 are considered vigorous (Pate, Pratt et al. 1995). In order to assign MET values to the individual components of occupational activity we utilized the self-reported measure of work intensity available in the CHNS which is derived from an interview in which respondents are asked about the activity required in their occupation(s) including standing, sitting, lifting, etc. Table 7 includes the specific occupations and the MET values assigned to each. If individuals reported hours worked in more than one job type, MET-hours per week values were summed to obtain a measure of overall occupational activity energy expenditure.

The following strategy was used to categorize total occupational activity: we determined the mean hours/week men and women in the longitudinal sample worked at baseline (men: 49 hours/week; women: 47 hours/week), and based the categorization upon what the MET-hours/week would be given a low (<3 METs), medium (3-6 METs), or high (≥6 METs) activity level. Categorizations are listed in Table 7. These cut-points were assigned to both the cross-sectional and longitudinal samples to provide comparable results across analyses.

c. Domestic activity

For an overall measure of domestic physical activity we used five different activities that were available in the 1997 and 2000 survey years reported in average hours per week spent in the last year. Specific domestic activities and MET intensity values as based on the

Compendium of Physical Activities (Ainsworth, Haskell et al. 2000) are listed in Table 7. While MET values in the Compendium were derived from, and thus may be more relevant to, individuals in high-income countries, we used the Compendium values because there is no similar reference for activity in China. Individual MET-hours per week values were then summed to obtain a measure of overall domestic activity energy expenditure.

Domestic activity was categorized as either 0 MET-hours/week (for those with none) or above/below the baseline sex-specific median of the longitudinal sample for those who reported >0 MET-hours/week. Resulting categorizations are listed in Table 7. Because it is possible that women, who spend the majority of their domestic time in childcare, double-counted hours/week while multi-tasking, we ran additional analyses excluding childcare but saw no substantial differences in results.

d. Transportation activity

Transportation activity data were derived from questions asking the round-trip commuting time to/from work, school, and/or shops via foot or bicycle. Because most individuals in China work a 6-day work week, we assumed a value of 6 days/week to calculate hours/week spent walking and/or bicycling for transportation purposes. Hours spent per week were multiplied by specific MET intensity values from the Compendium of Physical Activities (Ainsworth, Haskell et al. 2000) to assess energy expenditure.

Transportation activity was categorized as 0 MET-hours/week and then divided at the baseline sex-specific median of the longitudinal sample for those doing >0 MET-hours/week. Resulting categorizations did not differ between men and women and are listed in Table 7.

e. Sports and recreational activity

Adults in the CHNS were asked the average weekly time spent over the last year in specific sports and recreational activities more common in China, as listed in Table 7. Because sports and recreational activities were condensed into categories, to calculate energy expenditure we used the Compendium (Ainsworth, Haskell et al. 2000) to calculate a mean MET value for each category (see Table 7). Individual MET-hours per week values were then summed to obtain a measure of overall leisure activity energy expenditure.

Leisure activity was dichotomized as any versus none for both men and women due to the very little prevalence and limited change between 1997 and 2000 of leisure activity.

f. Total physical activity energy expenditure

Total energy expenditure was calculated by summing the MET-hours/week spent in occupational, domestic, transportation, and leisure physical activity. Categorization was based on quantiles of total energy expenditure from baseline values of the longitudinal sample.

g. Change in activity between 1997 and 2000

Change variables capturing shifts in activity between 1997 and 2000 were created in multiple ways in order to explore the best way to describe this change. Continuous change variables were created by subtracting year 1997 values from year 2000 values for each dimension of activity as well as total activity. Further, we assessed whether an individual changed categories of a specific dimension of activity between 1997 and 2000. For instance, if someone was below the median for transportation activity in 1997, but above the median (as defined in 1997) in 2000, this was categorized as having increased transportation activity. These categorizations were done in two ways: first, by combining all levels of increased activity into one category and all levels of decreased activity into another category; and, second, by further delineating whether an individual increased/decreased one or two levels of activity. Thus, if an individual increased from having 0 MET-hours/week of transportation activity in 1997 to above the median level in 2000, this would be captured as having increased 2 levels of transportation activity. For total activity, which was categorized in quantiles, an individual was able to increase/decrease their activity between 1997 and 2000 by one, two, or three levels depending upon into which quantile they were categorized in 1997 and in 2000 (based on 1997 definition). Thus, an individual in quantile 1 in 1997 and quantile 4 in 2000 would increase activity by 3 levels, while an individual in quantile 3 in 1997 and quantile 2 in 2000 would decrease activity by 1 level.

3. Statistical analysis

All analyses were stratified by gender to account for the different structure for men and women of the physical activity environment in China. Age and age-squared were used to model the observed curvilinear relationship between age and overweight/BMI in the data and were included in models along with baseline total energy intake (in kilocalories) as a continuous variable. Entered into the model as indicator variables were baseline deflated household income per capita divided into tertiles, comparing low income to middle or high income categories; education, which was categorized as having a primary school education or less, a middle school education, a high school education, or a college education; and urban (versus rural) residence.

In cross-sectional analyses we modeled the relationship between activity and overweight status using logistic regression. In longitudinal analyses we modeled the relationship between activity and continuous change in BMI using linear regression and the relationship between activity and weight maintenance using multinomial logistic regression. A summary of analyses is presented in the Appendix. Data management was handled in SAS version 8.2 (SAS Institute Inc., Cary, NC) and statistical procedures were implemented in Stata version 9.1 (Stata Corporation, College Station, TX).

C. Results

Table 8 shows characteristics of men and women at baseline (1997) stratified by overweight status (15.1% of men and 19.0% of women were overweight at baseline). Overweight prevalence was higher in older respondents, residents of an urban area, and those of middle or high income. Among men, overweight prevalence was highest in those with a middle school education and inversely decreasing with increasing education; however, overweight was lowest in those with a primary school education or less. In women, overweight prevalence was highest in those with a primary school education or less, with decreasing prevalence with increasing education. Lower occupational activity levels were associated with higher overweight in both sexes and higher domestic activity was associated with higher overweight in women. Higher transportation and leisure activity were associated, albeit not statistically significant, with lower overweight in both sexes.

1. Changes in body weight between 1997 and 2000

Of those surveyed in both years, body weight increased by a mean of 1.6 (SD=5.41) kg for men and 1.3 (SD=5.09) kg for women between 1997 and 2000. BMI increased by approximately 0.5 units for both men and women. Overall more men and women gained than maintained their weight between 1997 and 2000 (Figure 6). However, approximately 20% of men and women also lost weight. The vast majority of adults stayed in the normal weight category (BMI <25 kg/m^2), while approximately 9% became overweight (BMI ≥ 25 kg/m^2) (Figure 7). These changes represent a continuation of the trend of increasing body weight as seen in the CHNS.

2. Changes in physical activity between 1997 and 2000

While there have been dramatic decreases in MET-hours/week for occupational activity between 1997 and 2000, all other domains of physical activity have increased except for domestic activity for women, which decreased by 2.0 MET-hours/week (Figure 8). Decreases in total MET-hours/week are thus being driven largely by the occupational component of physical activity. Decreases in occupational energy expenditure for men and women and domestic energy expenditure for women represent a continuation of the trend seen in the earlier survey years of the CHNS; however, the increase in domestic activity for men seen between 1997 and 2000 is a reversal of the trend seen in the earlier survey years.

Mean weight change for men and women who decreased, maintained, or increased their physical activity between 1997 and 2000 is shown in Figure 9. Overall men and women who decreased their activity gained, on average, more weight than those who maintained their activity, who gained more than those who increased their activity.

3. Cross-sectional modeling results

We ran cross-sectional logistic regression models for survey years 1997 and 2000 (see Appendix, models 1-8). Results for models 2, 4, 6 and 8 are summarized in Table 9. Results using quantiles of total physical activity for men and women in both 1997 and 2000 show reduced odds of overweight with increasing physical activity in a dose-response manner. For example in women, the odds of being overweight are 14%, 38%, and 42% less for those in quantile 2, quantile 3, and quantile 4 vs. quantile 1, respectively. The majority of results are statistically significant; exceptions are quantile 2 for all samples except women in 2000, and quantile 3 for men in 2000.

When total physical activity is sub-divided into domains, increased occupational activity is consistently associated with reduced odds of overweight, except in women in 2000. Domestic activity shows a dose-response, statistically significant relationship only in men in 2000; and transportation activity indicates increasing odds of overweight with increasing activity for both sexes in 1997 and for men in 2000. Finally, any leisure activity generally shows an inverse relationship with overweight, but fails to ever reach statistical significance. Our results suggest that reduction of overweight associated with activity is driven mostly by the occupational component, with little contribution from the other domains of physical activity.

4. Longitudinal modeling results: linear

We began our longitudinal modeling using a linear model with change in BMI regressed on change in total activity (see Appendix, models 9-11). Total activity was coded continuously in model 9 and categorically (quantile) in models 10 and 11. Change in model 9 was calculated by subtracting total activity in 1997 from total activity in 2000, change in models 10 and 11 was determined by whether an individual had changed quantile of activity (calculated from baseline values) between 1997 and 2000. Model 11 differed from model 10 in that we allowed differentiation between level of increase/decrease, whereas in model 10 we pooled any increase or any decrease into 2 categories. Results (not shown) were, for the most part in the expected direction but not statistically significant. Any statistically significant results were found in men for decreases, not increases, in activity. There were no statistically significant results for women.

Linear models were also run with change in BMI regressed on change in the different domains of activity (Appendix, models 12-14). Continuous change in MET-hours/week was calculated for model 12 by subtracting 1997 values from 2000 values; change for models 13 and 14 was determined by whether an individual changed category between 1997 and 2000 (based on baseline values) and thus either increased or decreased their activity. Similar to the specification above, model 13 pooled any increase and any decrease, while model 14 allowed for a more specified detailing for increase and decrease. Results (not shown) were for the most part not statistically significant and mixed in direction. The only consistent result was for women where an increase in leisure activity resulted in a statistically significant decrease in BMI (coefficient: –0.8660, 95% CI: -1.4878, -0.2442).

5. Longitudinal modeling results: multinomial logistic

Because of the lack of consistent results seen in the linear models, we moved next to multinomial logistic regression (Appendix, models 15-30) with the dependent variable defined categorically as weight maintainers, weight losers, or weight gainers. Our rationale for using this specification was based on the minimal BMI change observed between 1997 and 2000, and that there would be a better chance of finding an impact of activity on weight status if we compared those who were weight gainers to those who were weight losers (i.e. comparison of more extreme observations). A failure to find an impact when comparing the extremes would more clearly show that changes in physical activity did not have the expected effect on weight status in the years between 1997 and 2000.

We began by regressing weight change category on change in total activity (see Appendix, models 15 and 16). Total activity was coded categorically, and change was determined by whether an individual had changed quantile of activity (calculated from baseline values) between 1997 and 2000. Model 16 differed from model 15 in that we allowed differentiation between level of increase/decrease, whereas in model 15 we pooled any increase or any decrease into 2 categories. Next, we regressed weight change category on change in the different domains of activity (Appendix, models 17 and 18). Change for models 17 and 18 was determined by whether an individual changed category between 1997 and 2000 (based on baseline values) and thus either increased or decreased their activity. Similar to the specification above, model 17 pooled any increase and any decrease, while model 18 allowed for a more specified detailing for increase and decrease.

Results from models 15 and 17 are presented in Table 10. The categories of weight maintenance and weight loss were compared to the weight gain category (referent). Further, increases and decreases in activity (either total or by domain) are compared to maintenance of activity level. For decreases in total activity, we see results in the correct direction for both men and women, but these results only reach statistical significance for men comparing losers to gainers (OR=0.72, 95% CI=0.55, 0.96), which we can interpret as weight losers are 28% less likely to decrease vs. maintain their total activity compared to weight gainers.

Increases in total activity, however, are often in the wrong direction, although none of them reach statistical significance.

Results for increases or decreases in the domains of activity are unclear. Only increases in leisure time activity for women comparing both maintainers (OR=2.99, 95% CI=1.05, 8.50) and losers (OR=3.59, 95% CI=1.16, 11.12) to gainers reach statistical significance. Results for the major component of physical activity, occupational activity, are in the right direction but fail to reach statistical significance, while results for the other domains are mixed.

Because of the lack of clear results in the previous models, we next compared the top and bottom 10% and 5% of change in total activity and domains of activity with those who were in the middle 90 or 95% of the sample (see Appendix, models 19-22). For example, total activity for men had a mean change of –21.7 MET-hours/week between 1997 and 2000, and –311.3, -226, +160.5, and +270.5 MET-hours/week represent the 5^{th}, 10^{th}, 90^{th}, and 95^{th} percentiles, respectively. In model 19 we compared those in the top 10% of increase (90^{th} percentile) and those in the top 10% of decrease (10^{th} percentile) to those in the middle 90%. We followed a similar modeling strategy for models 20-22, subdividing at the 5^{th} percentile, and using domain of activity to define the percentiles. Again we modeled using a multinomial logistic regression model, comparing weight gainers to weight maintainers and weight losers. When examining the tail ends of the distribution in this way, results (not shown) failed to become clearer.

Because occupational activity is the primary component of physical activity in this population, we were curious why we failed to see any clear results with this component even when examining the tail ends of the distribution. Thus, we subdivided the hours/week an individual worked in 1997 and 2000 into sedentary, moderate, or vigorous hours/week using the self-reported measure of work intensity. Changes in sedentary, moderate, and vigorous occupational hours/week were calculated by subtracting 1997 values from 2000 values. The top and bottom 10% and 5% of these distributions were then used to categorize individuals. For example, the mean change in vigorous hours/week for men was –2.14; and –56, -40, +36, and +50 hours/week represent the 5th, 10th, 90th, and 95th percentiles, respectively. These comparisons were modeled in multinomial logistic regression models (see Appendix, models 23 and 24) again where weight gainers were compared to weight maintainers and weight losers. Results (not shown) were not clear when comparing weight gainers to weight maintainers. However, when comparing weight gainers to weight losers we found that both men and women who lost weight were more likely to be in the top 90% (i.e. increased vigorous work hours) than in the bottom 10% (i.e. decreased vigorous work hours), compared to those that gained weight, although results did not reach statistical significance.

Our final multinomial logistic regression models regressed weight change category (maintain, lose, gain) on baseline categorizations of total activity and domains of activity (see Appendix, models 25-30). Models 25, 27, and 28 evaluated total activity categorized by baseline quantile (model 25), baseline top/bottom 10 percent (model 27) and baseline top/bottom 5 percent (model 28); models 26, 29, and 30 evaluated domains of activity categorized by baseline value of occupational, domestic, transportation, and leisure activity (model 26), baseline top/bottom 10 percent by domain (model 29) and baseline top/bottom 5 percent by domain (model 30). These models predict future weight change (maintenance, loss, gain) by baseline activity status, rather than change in activity. Results (not shown) comparing weight gainers to weight losers (the more extreme of the comparisons) failed to reach statistical significance and were for the most part mixed and lacked clarity.

6. Longitudinal modeling results: logistic

For our final longitudinal models we regressed overweight status in 2000 on baseline activity values, both total and by domain, controlling for baseline overweight status (see Appendix, models 31-38). Baseline total activity (model 31) was categorized by quantile, and baseline activity values of the different domains (model 32) were categorized as specified in Table 7. Models 33 and 34 examined the top and bottom baseline 10^{th} and 5^{th} percent of the distribution of total activity, models 35 and 36 examined these distributions by domain of activity, and models 37 and 38 looked at baseline sedentary or vigorous occupational activity.

Results for models 31 and 32 are presented in Table 11. Results for total activity in women show the expected inverse relationship of likelihood of overweight with increases in activity, although we do not see a clear dose-response relationship and the only value to reach statistical significance is comparing women in quantile 3 to those in quantile 1 (OR=0.67, 95% CI=0.46, 0.99). In men, we fail to see the expected inverse relationship and instead see results suggesting increasing likelihood of overweight with increasing activity by quantile, although none of these reach statistical significance. Results when activity is subdivided by domain are mixed and unclear. We see the expected inverse dose-response relationship with overweight only with men and domestic activity, while this relationship shows the opposite effect in women. A similar direct relationship with overweight is seen with transportation activity among women, with no effect seen among men. Again, we see an opposite effect among men and women with leisure activity, with an increasing likelihood of overweight with any activity for men, and a decreasing likelihood of overweight with any activity for women. Finally, occupational activity is in the expected direction for men and women at high levels, but medium levels have no effect in men and a direct effect in women compared to low levels of occupational activity. It is important to note that despite the confusing and misleading directional effects of these relationships, none failed to reach statistical significance at $p<0.05$.

Results failed to become clearer when examining the extreme top/bottom 10% and 5% of the distribution (models 33-36, results not shown). Results hovered around the null value, were inconsistently in the expected direction, and failed to reach statistical significance in any comparison. In further models we looked at baseline values of sedentary (compared to moderate and vigorous), and vigorous (compared to moderate and sedentary) hours of occupational activity per week (models 37 and 38, results not shown). Results showed that sedentary hours of occupation predicted increased likelihood of overweight, while vigorous hours of occupation predicted decreased likelihood of overweight, although results were not statistically significant after controlling for baseline overweight status.

D. Discussion

In these analyses we examined the impact of changes in total physical activity as well as changes in domains of physical activity on weight in adult Chinese men and women over a three-year period. Descriptively we have shown that between the 1997 and 2000 survey years of the CHNS there has been on average a 6.5% and 4.3% increase in the prevalence of overweight in adult men and women, respectively. Further, we show that during this time period more adults are gaining than maintaining weight, a troubling statistic. On average, there have been declines in energy expended at work, but little change in that expended during domestic, transportation, or leisure. In cross-sectional analyses we found a significant inverse effect of total and occupational activity on overweight status in men and women in 1997 and 2000, and an inverse effect of domestic activity in men in 2000. In longitudinal models we found a significant effect on weight loss of increased leisure activity (sports and/or exercise) in women as well as for decreased total activity in men, but the majority of our cross-sectional results were not reproducible in longitudinal models, despite multiple modeling strategies.

In earlier analyses using these data we showed that both occupational and domestic activity affect overweight status in men and women over a longer time period (1991 to 2000). Our aim with the analyses in this paper was to ask whether we could look beyond occupational and domestic activity in a more multidimensional manner, and additionally consider transportation and leisure sources of physical activity, albeit over a much shorter time period (1997-2000) for which there was data available.

In Table 12 we present a comparison of results from our earlier analyses and similarly specified results from data used for the analyses presented herein. First, one will note the differences in sample size, understandable because the time period is so much shorter for the latter analysis, and thus there is considerable less power to find an effect. Second, while we see the same direction of effect for occupational and domestic activity in men, these values are much closer to the null and fail to reach statistical significance. Third, in women we are unsuccessful in replicating the direction of effect for either occupational or domestic physical activity. The values for occupational activity are much closer to the null, and those for domestic activity are very imprecise compared to the earlier results. As would be expected, precision for the latter results is less than that for the earlier results in all cases; however, while those for occupational activity for men and women and domestic activity for men are not greatly divergent, those for domestic activity for women are considerably larger.

Between 1997 and 2000 we see increases in overweight and decreases in energy expenditure that are mostly consistent with the trends seen from earlier years, shown graphically in Figures 10 and 11. Occupational activity is clearly decreasing in MET-hours/week between 1991 and 2000 for men and women, as is domestic activity for women. However, we do see an increase in domestic activity for men between 1997 and 2000 (also refer to Figure 8), although this change is minimal. Similarly, the prevalence of overweight has continued to increase between 1991 and 2000, with no lessening of this trend between 1997 and 2000. Nonetheless, the overall increase in overweight and the overall decrease in energy expenditure is much greater between 1991 and 2000 than in the shorter period between 1997 and 2000; thus, while a larger decrease over a longer time period (with a larger sample) was adequate to find a longitudinal effect of activity on overweight, it is not unreasonable that we are not able to replicate this finding with a smaller change over a shorter time period with a smaller sample.

We ran many different kinds of longitudinal models in attempts to find an effect of different domains of activity on weight status. While lack of an effect could be interpreted as activity change having no effect on weight status, this is not only implausible, but also unlikely due to our earlier results as well as other published research using these data (Paeratakul, Popkin et al. 1998; Bell, Ge et al. 2001). Rather, we feel that analyses should be revisited in later waves of the CHNS when more data on transportation and leisure activity data are available. Lack of a longitudinal effect could also be an indication that the increases in overweight are due to some other factor, one either not controlled for or incompletely controlled for in the analyses. The most obvious alternative factor is energy intake. While we did control for total energy intake in our models, it did not consistently explain change in BMI or weight status, although this was less true for men than for women. We recognize that inclusion of total energy intake at baseline does not, by any means, constitute complete adjustment for caloric intake in these analyses. It is certainly possible that individuals compensate for changes in energy expenditure from physical activity by changing energy intake. However, we did run analyses where we controlled for change in total energy intake with no difference in results. Additional analyses utilizing more accurate measures of energy intake would be helpful in determining if caloric compensation effects can explain the present results.

In the analyses presented in Table 10 we found that for men and women, weight losers were less likely to increase than maintain their total activity compared to weight gainers, a counterintuitive result. Although this result was not statistically significant, we were interested to see if we could find what was driving it by looking more closely at those who increased activity ("increasers"), versus those who decreased activity ("decreasers"). Focusing explicitly on occupational activity, we found that while increasers and decreasers similarly changed the absolute value of hours/week worked between 1997 and 2000, the change in intensity did not differ. Thus those who increased their physical activity appear to be working substantially more hours, but not increasing the intensity of those hours. An increase in sedentary work hours, while it adds to overall energy expenditure as we have determined it, does not intuitively translate into activity that will lead to weight loss. It is possible that these individuals have substituted sedentary work hours for more physically strenuous activity not captured in the survey.

It was for the above reason, and also because our measures of occupational energy expenditure at work do not account for changes in activity level within occupations over time, that we looked particularly at occupational activity subdivided by the intensity of the hours worked per week. This intensity measure is captured independently of job classification. While the effect was not statistically significant, we did find that men and women who lost weight were more likely to be in the top 10% of the distribution increasing their amount of vigorous work hours between 1997 and 2000 than in the top 10% of those decreasing their amount of vigorous work hours, compared to those that gained weight. Further, when looking at baseline values of sedentary and vigorous work hours predicting overweight status three years later, we find that hours spent in vigorous work (as compared to sedentary or moderate work) is associated with less likelihood of obesity; and that hours spent in sedentary work (as compared to moderate or vigorous work) is associated with a higher likelihood of obesity. These results are comparable to those reported in two studies of occupational sitting time that found those who reported high daily levels of sitting were significantly more likely to be overweight or obese than those reporting low daily levels (Brown, Miller et al. 2003; Mummery, Schofield et al. 2005).

To our knowledge there have been no other studies investigating the simultaneous effect of occupational, domestic, transportation, and leisure sources of physical activity on weight status or change. The importance of examining multiple domains of physical activity simultaneously has been made clear in numerous studies which demonstrate that focusing on only one type of physical activity may not only underestimate overall activity (King, Fitzhugh et al. 2001; Craig, Brownson et al. 2002; Tammelin, Nayha et al. 2002), but also misclassify individuals as less active than they really are (Vaz and Bharathi 2004).

Consistent with our cross-sectional findings, many studies have reported significant inverse relationships between weight and one domain of activity while failing to find a similar relationships with other domains of activity (Ball, Owen et al. 2001; King, Fitzhugh et al. 2001; Gutierrez-Fisac, Guallar-Castillon et al. 2002). Further, other investigators have found a relationship with BMI using a composite of work, leisure, and home activity as a measure of total physical activity (Slattery, Sweeney et al. 2006). One other study reported both cross-sectional and prospective associations between physical activity and body weight, and similar to our findings, they report a significant cross-sectional association at both baseline and follow-up, but found no relationship between baseline activity and subsequent weight gain (Williamson, Madans et al. 1993).

Prospective observational studies are fewer and results are less consistent; however, the majority report at least one significant inverse association between physical activity and weight status. Comparable to our longitudinal results, many reported associations were not in the expected direction, and gradients of activity were often unclear (Ball, Brown et al. 2002; Ekelund, Brage et al. 2005; Yang, Telama et al. 2006). Inconsistent results both within and between studies are likely partially attributable to the difficulty in measuring physical activity, a highly complex behavior that can be differentially affected by recall. Additionally, the modeling strategies employed are highly varied: exposures can be measured at baseline, at follow-up, retrospectively, or at multiple time points, and outcome variables can be defined in a multitude of ways.

One review of the literature using data from observational cohort studies (Fogelholm and Kukkonen-Harjula 2000) concluded that there is inconsistent evidence of the predictive effect of physical activity on weight gain, with results highly dependent on study design. Results using measurement of activity at follow-up or at both baseline and follow-up, although modest, were more consistently associated with weight than those using measurements of activity at baseline. A subsequent review (Wareham, van Sluijs et al. 2005) concludes that the majority of studies find an inverse association between physical activity and weight gain, again with a small overall magnitude of effect. The authors further state that the predominance of recent studies in the expected direction (more so than the earlier review) could be due to (1) increased sample sizes and (2) a manifestation of publication bias given the plausibility of an association between inactivity and weight gain.

Several limitations of this study should be acknowledged. First, all physical activity data were based on self-report. Even when questionnaires, such as ours, are constructed with attention to the different domains of activity, they are still subject to measurement error and can be relatively imprecise as a measure of total energy expenditure. Nonetheless, the size of large cohort studies such as the CHNS necessitates measurement of physical activity by questionnaire; and while some studies have shown that overweight individuals tend to over-report their physical activity (Lichtman, Pisarska et al. 1992; Buchowski, Townsend et al. 1999), the majority of this work has been done in populations from higher-income countries rather than in lower-income developing countries where the stigma with being overweight is less established. Second, the use of job description to assess energy expenditure has been criticized because it can be subject to mis-measurement due to within-job variability and job intensity misclassification (Evenson, Rosamond et al. 2003; Vaz and Bharathi 2004). However, it has been shown that methods similar to ours of assessing occupational activity by way of hours worked per week and the average MET intensities of job activities provide good validity (Ainsworth, Jacobs et al. 1993). Finally, using METs to quantify energy expenditure does not take into account individual differences such as age, sex, and geographic and environmental conditions that may alter the energy cost of movement (Ainsworth, Haskell et al. 2000). Further, MET values assigned in the Compendium, which are derived from individuals in high-income countries, may differ from the true energy cost of activities in China. For instance, while ping-pong is played as a non-competitive casual activity in the U.S., it can be a highly vigorous and competitive sport in China. Thus, MET values may over- or under-estimate true energy expenditure. However, there is no similarly designed reference specific to China, and despite its limitations, the MET approach remains the best available way to systematically apply energy cost estimates in self-report measures (Matthews 2002).

The main strengths of the study were our utilization of different domains of activity allowing for a more complete assessment of total activity; and not only did we assess type of activity, but also considered intensity, frequency, and duration. Moreover, we were able to get a detailed assessment of occupational activity that took into account not only standard market-based jobs (such as manufacturing or office work) but also home-based wage work such as raising livestock, fishing, or running a small home business. These types of jobs are more prone to not be reported due to the fact that they are often done in addition to a standard market-based job. Additionally, we have found that capturing work completed in home-based jobs is particularly important for women, who not only tend to undertake much more of this type of work than men, but also to have more than one type of job. Further, we utilized several different modeling strategies, both cross-sectional and longitudinal, to provide a thorough analysis of the relationship between weight and activity.

In conclusion, in this study of the effect of different domains of physical activity on weight status in adult men and women in China, we found significant inverse associations of total and occupational physical activity in men and women cross-sectionally, but few significant associations longitudinally. The number of studies investigating the prospective relationship between activity and weight in adults is still relatively small, especially in developing and transitioning countries, and despite the plausibility of this relationship, studies vary in their conclusions due to issues of confounding, reverse causality, and measurement error. Thus, we feel that regardless of the lack of easily interpretable results in this study, they are nonetheless an important addition to that small literature. The nutrition transition in China is highly likely to continue unabated in years to come, with further urbanization bringing along with it additional increases in sedentary jobs, motorized transportation, and access to labor-saving devices, both in the home and in the workplace. While the results of the current study do not provide conclusive evidence, we are hopeful that future research over a longer time period on this diverse and informative sample of Chinese adults will add to the evidence base in such a way to allow more specific public health recommendations concerning the prevention of overweight and obesity.

Table 7. Categorizations used in analyses and types of activities composing the domains of physical activity

Domain	Cut-points (MET-hours/week)	Specific occupations/activities (METs)
Occupational	Men: <147, ≥147-<294, ≥294 Women: <141, ≥141-<282, ≥282	Light (2.0): Senior or junior professional; administrator; manager; office staff; army or police officer; commerce- or service-based home business Moderate (4.0): Skilled or non-skilled worker; driver; homemaker; student; manufacturing, peddling, or construction home business Vigorous (6.0): Work in farming, fishing, garden/orchard, livestock
Domestic	Men: 0, >0-<10.9, ≥10.9 Women: 0, >0-<42, ≥42	Preparing food (2.25), buying food (2.3), laundry (2.15), cleaning house (3.0), childcare (2.75)
Transportation	Men/women: 0, >0-<10.5, ≥10.5	Walking (3.5), bicycling (4.0)
Leisure	Men/women: Any/none	Martial arts (10.0); jogging or swimming (7.0); dancing or acrobatics (5.25); basketball, volleyball, or soccer (6.3); badminton, tennis, or ping-pong (5.2)

Table 8. Baseline (1997) characteristics of men and women stratified by overweight status

	Men		Women	
	Not overweight (N=2696)	Overweight (N=480)	Not overweight (N=2716)	Overweight (N=636)
Age (years)	35.9 ± 10.4	39.2 ± 8.9***	36.0 ± 10.0	40.6 ± 8.9***
Urban residence	24.9	45.4**	27.2	33.3**
Income (tertiles)				
Low	35.9	19.4[a]	35.2	24.7[a]
Middle	33.4	32.1[b]	33.3	35.4[b]
High	30.7	48.5[c]	31.5	40.0[b]
Education				
None/primary	29.9	16.7[a]	43.8	54.0[a]
Middle school	45.3	41.4[b]	35.1	29.9[b]
High school	16.7	25.2[c]	13.2	11.0[b]
College/technical	8.1	16.7[c]	8.0	5.1[b]
Occupational activity[†]	230.9 ± 158.5	170.1 ± 127.3**	210.9 ± 147.4	194.6 ± 140.1*
Domestic activity [†]	8.4 ± 16.0	9.5 ± 14.7	40.1 ± 28.0	47.1 ± 30.7***
Transportation activity[†]	10.3 ± 12.0	11.1 ± 11.4	9.9 ± 10.8	10.1 ± 10.1
Leisure activity[†]	1.5 ± 8.2	1.4 ± 7.0	0.7 ± 5.1	0.3 ± 3.8

Continuous variables are mean (standard deviation), categorical variables are proportions.
*p<0.05; **p<0.01, ***p<0.001, [†]MET-hours/week
[a,b,c] Within income and education categories, proportions that differ from one another by ANOVA at p<0.05 noted with different letters

Table 9. Results from cross-sectional logistic models of total and domains of physical activity on overweight† status in men and women, 1997 and 2000

	1997		2000	
	OR†	95% CI†	OR	95% CI
Men				
Total activity				
Quartile 2‡	0.97	0.72, 1.30	0.97	0.77, 1.22
Quartile 3	0.73*	0.54, 1.00	0.81	0.63, 1.04
Quartile 4	0.42***	0.29, 0.60	0.66**	0.51, 0.87
Occupational activity				
Medium‡	0.71*	0.54, 0.94	0.73*	0.57, 0.94
High	0.38***	0.26, 0.56	0.59**	0.42, 0.82
Domestic activity				
Medium	0.81	0.60, 1.10	0.74*	0.56, 0.97
High	0.86	0.65, 1.14	0.70**	0.54, 0.91
Transportation activity				
Medium	1.99**	1.34, 2.95	1.29	0.93, 1.79
High	1.96**	1.33, 2.88	1.14	0.83, 1.57
Leisure activity				
Any‡	0.63	0.39, 1.03	0.91	0.58, 1.41
Women				
Total activity				
Quartile 2	0.86	0.66, 1.11	0.77*	0.62, 0.95
Quartile 3	0.62***	0.47, 0.81	0.75*	0.60, 0.94
Quartile 4	0.58***	0.44, 0.76	0.68**	0.53, 0.86
Occupational activity				
Moderate	0.73*	0.56, 0.94	0.92	0.72, 1.19
High	0.65**	0.49, 0.88	1.00	0.74, 1.35
Domestic activity				
Medium	0.86	0.50, 1.47	1.08	0.61, 1.91
High	0.99	0.57, 1.71	1.19	0.67, 2.13
Transportation activity				
Medium	1.59**	1.15, 2.20	0.95	0.67, 1.34
High	1.34	0.97, 1.84	0.75	0.53, 1.04
Leisure activity				
Any	0.77	0.40, 1.48	1.51	0.88, 2.58

Models controlled for age, urban residence, income, education, and total energy intake

†OR=odds ratio; CI=confidence interval; overweight=BMI≥25 kg/m^2

*p≤0.05, **p<0.01, ***p<0.001

‡Referents are Quartile 1 for total activity, Low activity for occupational, domestic, and transportation activity, and None for leisure activity.

Table 10. Results from multinomial logistic models of total and domains of physical activity on weight change category§ in men and women, 1997-2000

	Men		Women	
	OR†	95% CI†	OR	95% CI
Weight Maintainers‡				
Total activity				
Increase total activity	1.00	0.77, 1.31	0.87	0.67, 1.12
Decrease total activity	0.92	0.73, 1.15	0.85	0.69, 1.05
Occupational activity				
Increase activity	1.15	0.80, 1.65	1.12	0.78, 1.59
Decrease activity	0.85	0.62, 1.17	0.91	0.67, 1.23
Domestic activity				
Increase activity	1.36	0.98, 1.87	0.86	0.61, 1.21
Decrease activity	1.08	0.78, 1.49	0.94	0.70, 1.26
Transportation activity				
Increase activity	0.91	0.67, 1.25	1.07	0.80, 1.44
Decrease activity	0.96	0.70, 1.33	0.96	0.70, 1.31
Leisure activity				
Increase activity	1.13	0.61, 2.12	2.99*	1.05, 8.50
Decrease activity	1.02	0.52, 2.02	1.76	0.71, 4.40
Weight Losers‡				
Total activity				
Increase total activity	0.81	0.58, 1.14	0.95	0.70, 1.29
Decrease total activity	0.72*	0.55, 0.96	0.90	0.70, 1.17
Occupational activity				
Increase activity	1.10	0.70, 1.75	1.22	0.80, 1.87
Decrease activity	0.78	0.52, 1.18	0.88	0.60, 1.29
Domestic activity				
Increase activity	1.38	0.92, 2.09	0.96	0.64, 1.44
Decrease activity	1.11	0.73, 1.68	0.71	0.49, 1.04
Transportation activity				
Increase activity	1.48	1.00, 2.19	1.20	0.83, 1.73
Decrease activity	1.11	0.73, 1.71	1.05	0.71, 1.57
Leisure activity				
Increase activity	0.87	0.37, 2.06	3.59*	1.16, 11.12
Decrease activity	0.77	0.29, 2.03	1.10	0.34, 3.57

Models controlled for age, urban residence, income, education, and total energy intake
§Weight change defined as weight maintenance (±3% body weight), weight gain (gain ≥3% body weight), and weight loss (lose ≤3% body weight)
†OR=odds ratio; CI=confidence interval; *p<0.05
‡Weight maintenance and weight loss categories are compared to the weight gain category

Table 11. Results from longitudinal logistic models of total and domains of baseline physical activity on overweight† status in men and women, 1997 and 2000

	Men		Women	
	OR†	95% CI†	OR	95% CI
Total activity				
Quartile 2‡	1.44	0.92, 2.26	0.86	0.59, 1.27
Quartile 3	1.28	0.82, 2.01	0.67*	0.46, 0.99
Quartile 4	1.21	0.76, 1.95	0.82	0.56, 1.21
Occupational activity				
Medium‡	1.01	0.69, 1.47	1.12	0.78, 1.60
High	0.89	0.56, 1.41	0.95	0.63, 1.44
Domestic activity				
Medium‡	0.85	0.57, 1.27	2.23	0.85, 5.84
High	0.75	0.50, 1.11	2.63	1.00, 6.86
Transportation activity				
Medium‡	0.98	0.61, 1.57	1.11	0.71, 1.74
High	1.00	0.64, 1.57	1.27	0.82, 1.96
Leisure activity				
Any‡	1.24	0.62, 2.50	0.92	0.36, 2.35

Models controlled for age, urban residence, income, education, total energy intake, and baseline overweight status

†OR=odds ratio; CI=confidence interval; overweight=BMI≥25 kg/m^2; *$p<0.05$

‡Referents are Quartile 1 for total activity, Low activity for occupational, domestic, and transportation activity, and None for leisure activity

Table 12. Comparison of logistic regression results for occupational and domestic activity on overweight between survey years 1991-2000 and 1997-2000

	1991-2000 (N=4708 men, 4697 women)			1997-2000 (N=1791 men, 1922 women)		
	OR	95% CI	Precision	OR	95% CI	Precision
Men						
Occupational activity						
<120 MET-hrs/wk	Ref			Ref		
120-240 MET-hrs/wk	0.68**	0.55, 0.85	1.55	0.83	0.56, 1.23	2.20
≥240 MET-hrs/wk	0.41**	0.31, 0.53	1.71	0.91	0.59, 1.39	2.36
Domestic activity						
Any MET-hrs/wk	0.63**	0.52, 0.75	1.44	0.81	0.60, 1.09	1.82
Women						
Occupational activity						
<120 MET-hrs/wk	Ref			Ref		
120-240 MET-hrs/wk	0.80*	0.65, 0.98	1.51	1.05	0.73, 1.51	2.07
≥240 MET-hrs/wk	0.57**	0.45, 0.71	1.58	1.08	0.73, 1.60	2.19
Domestic activity						
0 MET-hrs/wk	Ref			Ref		
>0 to <50 MET-hrs/wk	0.77	0.53, 1.11	2.09	1.88	0.79, 4.46	5.65
50-200 MET-hrs/wk	0.68*	0.46, 0.99	2.15	2.21	0.91, 5.30	5.82
≥200 MET-hrs/wk	0.65	0.33, 1.26	3.82	4.14	0.75, 226.61	302.15

Models controlled for age, urban residence, income, education, and total energy intake. Models for the 1997-2000 analysis are further controlled for baseline overweight status.
*p<0.05; **p≤0.001

Figure 6. Proportion of adult men and women who maintained, lost, or gained weight between 1997 and 2000 in the CHNS

Figure 7. Proportion of adult men and women who stayed normal weight or overweight, or became normal weight or overweight between 1997 and 2000 in the CHNS

Figure 8. Mean changes in total and domains of physical activity between 1997 and 2000 for adult men and women in the CHNS

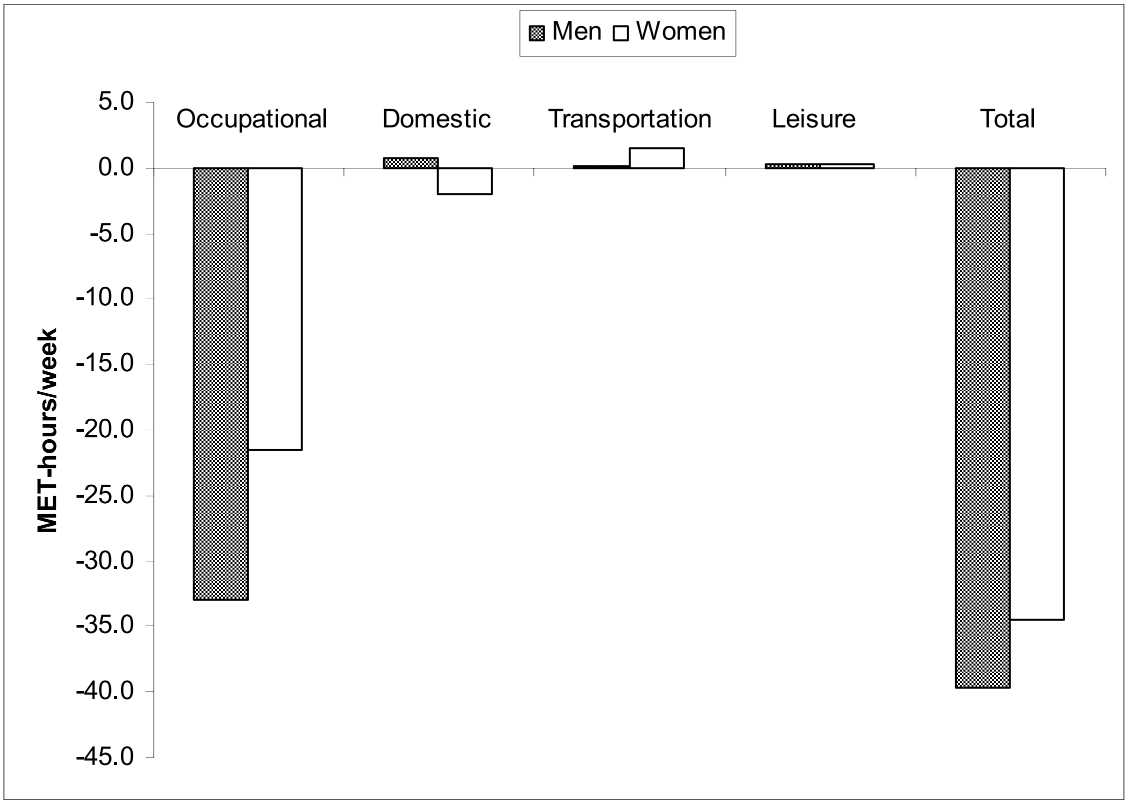


Figure 9. Average weight change by physical activity change between 1997 and 2000 for adult men (A) and women (B) in the CHNS

(A)

(B)

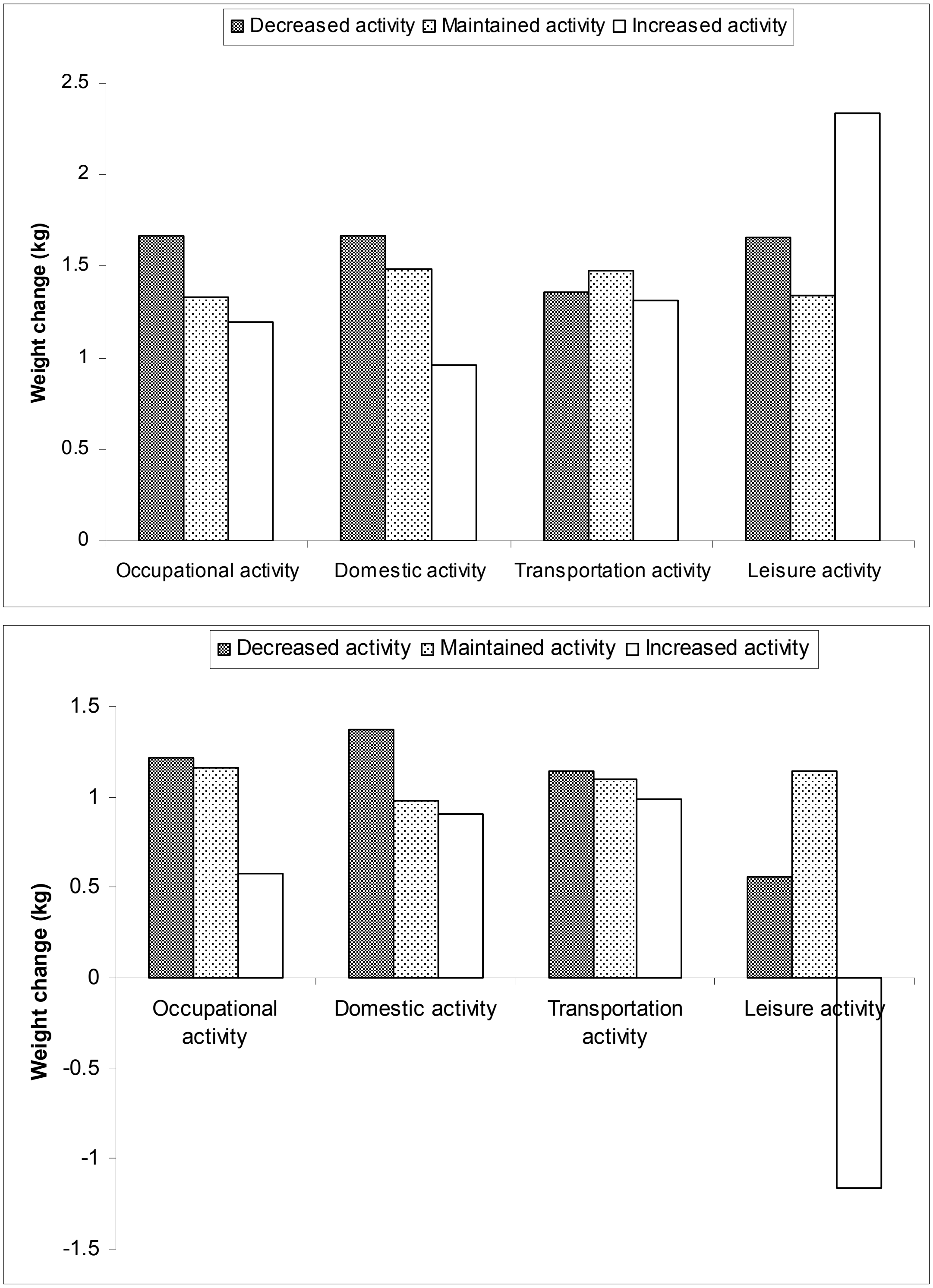


Figure 10. Trends in the prevalence of overweight (BMI≥25 kg/m^2) for adult men and women between 1991 and 2000 in the CHNS

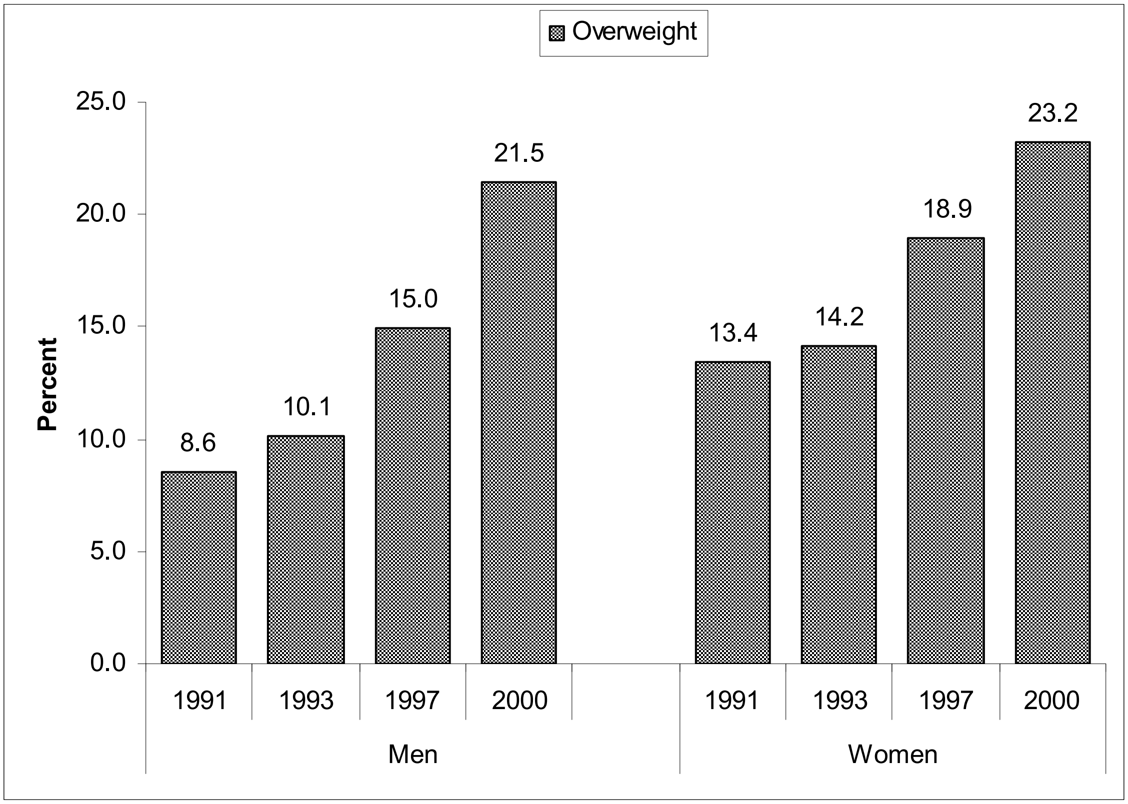
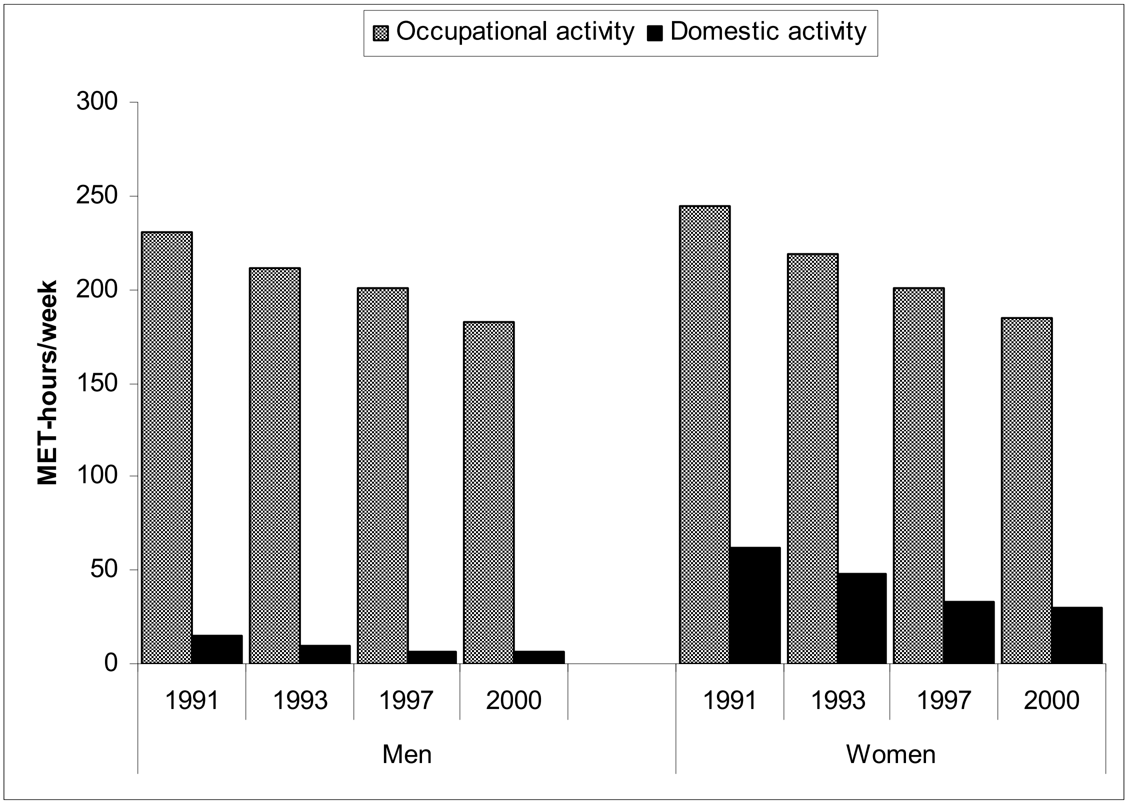


Figure 11. Trends in average occupational and domestic activity in MET-hours/week for adult men and women between 1991 and 2000 in the CHNS



VII. Synthesis

A. Overview of findings

This research investigates the effects of urbanicity on physical activity patterns and the effect that these multi-dimensional physical activity patterns have on the weight status of adults. We used data from multiple waves of the longitudinal China Health and Nutrition Survey, a survey designed to study how the social and economic transformation of Chinese society is affecting the health and nutritional status of its population. Detailed individual-level physical activity data from different domains was collected along with measured height and weight; and community-level information from the physical, social, and economic environments was collected to create a specific and multi-dimensional urbanicity index. In this research we first examined the direct effect that urbanization has had on the occupational physical activity patterns of Chinese adults. Second, we investigated the effect of both occupational and domestic energy expenditure on weight. Finally, we aimed to increase the scope of our earlier analyses by including transportation and leisure time physical activity in longitudinal investigations of activity on weight status. Below, we briefly summarize our findings and then provide a synthesis of our overall research.

1. China's transition: Measuring the dimensions of urbanization captures major shifts in adult physical activity patterns.

Using a longitudinal sample of Chinese adults from the 1991, 1993, and 1997 survey years of the CHNS, our objective was to determine the effect that urbanization in China has had on the occupational physical activity patterns of adults. We hypothesized that the level of urbanization of a community has an independent impact on the intensity of the occupational activity of the adults that live within that community. Using a multilevel approach which controlled for clustering within individuals as well as within communities, we were able to estimate the effect of community-level urbanicity as an independent risk factor for declining occupational activity while accounting for individual-level predictors. Through our use of a detailed 100-point index measure of urbanization that assessed multiple components of infrastructure, economic, and demographic factors, and was developed specifically for the CHNS, we were able to vastly improve our ability to discern influences of urbanization over the urban/rural dichotomy which is commonly used in research but fails to capture a great deal of heterogeneity within urban and rural environments.

Our results showed that community-level urbanization was significantly associated with occupational activity among men and women after adjustment for individual-level sociodemographic factors. Further, community-level urbanization was a more important determinant of occupational activity level than individual-level factors including income, age, and education. Coefficients from models translated into an increased risk of light occupational activity of 68% for men and 51% for women. By including time in our models as a fixed effect, we were able to assess whether the odds of having light occupational activity changed over time, and saw that adding community-level urbanization explained much of this time effect, but adding individual-level predictors did not. Further, by interacting time with urbanization we were able to test whether the impact of urbanization on occupational activity differed over time. We did not find a significant time by urbanization interaction, suggesting that urbanization's effect on occupational activity did not varying over time; rather, that during the time period surveyed this relationship was constant.

2. Longitudinal relationships between occupational and domestic physical activity patterns and body weight in China

Using data from the 1991, 1993, 1997, and 2000 survey years of the CHNS, our objective was to quantify energy expenditure from occupational and domestic physical activity and to determine the relationship between these two types of energy expenditure and body weight in Chinese adults. We hypothesized that both occupational and domestic energy expenditure would show an inverse relationship with body weight after controlling for socioeconomic and demographic factors. Further, we hypothesized that ownership of certain domestic labor-saving devices would be associated with body weight, also after controlling for socioeconomic and demographic factors. We used longitudinal linear random effects models to investigate the relationship of occupational and domestic activity to weight, as well as to investigate the relationship of ownership of household goods to weight. Random effects models adjust for the correlation between repeated observations taken in the same subject, thus correcting the biases in parameter estimates and providing correct standard errors and as a result correct confidence intervals and significance tests.

Descriptively we demonstrated in both men and women how energy expenditure from occupational and domestic sources has decreased, and how the prevalence of overweight has increased over the study period. In further descriptive analyses we showed how the acquisition of labor-saving household devices has multiplied, and how the occupational structure of the environment has changed towards a more sedentary one. Longitudinal modeling results showed that the net effect of increasing occupational physical activity resulted in overall lower body weight in both men and women, and increasing domestic physical activity resulted in overall lower body weight in men. Specifically, high levels of occupational energy expenditure resulted in a reduction of weight, on average, of 0.5 and 0.4 kg in men and women, respectively, versus low levels of occupational energy expenditure. Additional longitudinal modeling results showed how the net effect of ownership of various labor saving household devices resulted in overall increases in body weight in both men and women. Specifically, ownership of a refrigerator resulted in a reduction of weight, on average, of 1.4 and 1.3 kg in men and women, respectively.

3. Assessing the cross-sectional and longitudinal effect of multiple domains of physical activity in China: Do they matter for overweight status?

Using data from the 1997 and 2000 survey years of the CHNS, our objective was to quantify energy expenditure from occupational, domestic, transportation, and leisure time physical activity and to determine the relationship between these different types of energy expenditure and measures of weight status in Chinese adults. This study followed from the previous one by adding two more sources of physical activity to our analyses. This unfortunately required us to only utilize two waves of the survey due to 1997 being the first year in which transportation and leisure time activity were captured. We hypothesized that in cross-sectional analyses higher levels of energy expenditure from physical activity, regardless of domain, would be associated with reduced likelihood of overweight; further, that changes in energy expenditure from physical activity would partially explain weight changes over the three-year period. We used logistic models to investigate the cross-sectional relationship of energy expenditure from the different domains of physical activity to overweight status. We used multiple longitudinal modeling strategies to investigate the effect of change in energy expenditure on change in weight status, including linear models, multinomial logistic models, and logistic models.

Descriptively we showed how between 1997 and 2000, both men and women were more likely to have gained than maintained or lost weight. While the majority of individuals stayed within the normal weight category (BMI<25 kg/m^2), approximately 9% of men and women became overweight (BMI≥25 kg/m^2), a large increase over a three-year period. In additional descriptive analyses we demonstrated that while occupational energy expenditure declined dramatically between 1997 and 2000, both transportation and leisure time energy expenditure showed slight increases, and domestic energy expenditure decreased in women only. In cross-sectional analyses we found a significant inverse effect of total and occupational activity on overweight status in men and women in 1997 and 2000, and an inverse effect of domestic activity in men in 2000. In multinomial logistic longitudinal models we found a significant effect on weight loss of increased leisure time activity in women as well as for decreased total activity in men, but the majority of our cross-sectional results were not reproducible in longitudinal models.

B. Strengths and Limitations

One of the biggest challenges in doing physical activity research is measuring physical activity itself. Physical activity is a complex behavior encompassing many different forms and domains that may be difficult to recall. Our assessments used physical activity data based on self-report, which are subject to measurement error and recall bias, and can be relatively imprecise as a measure of energy expenditure. While the utilization of objective measures of activity are in some cases preferred, not only does the size and complexity of large surveys such as the CHNS necessitate the use of self-report measures due to practicality and cost issues, but, more importantly, in these analyses we were interested in domain-specific energy expenditure while objective measures would give us measures of total energy expenditure for the most part. In transitioning societies such as China where shifts are occurring in multiple domains of activity, it is essential to understand the importance of specific domains if successful interventions and policies are to be implemented.

Furthermore, the CHNS questionnaire was structured so that we were able to capture not only type, but duration, frequency, and intensity of activity as well, which provides us with measures of all the necessary dimensions of activity to assess energy expenditure. There is evidence that overweight individuals may over-report their physical activity, potentially leading to misclassification for more overweight as compared to normal weight individuals, resulting in an attenuation of the effect of activity on overweight. While this may be occurring in our research, we found no studies on selective over-reporting of activity in the literature in the Chinese population and postulate that because the stigma of being overweight is less established in China, over-reporting may be less of an issue. Nonetheless, the difficulty in recalling physical activity may lead to misclassification regardless of overweight status. This non-differential misclassification tends to produce estimates that are diluted, or closer to the null than the actual effect. Further, by categorizing individuals into levels of energy expenditure (e.g. low, medium, high) based on the total MET-hours/week as we have done in this research, some individuals will still be misclassified, but the majority will be ranked in the appropriate category regardless of some degree of measurement error.

Another difficulty lies in using METs as a way to quantify energy expenditure. First, METs do not take into account individual differences arising due to age, sex, and geographic and environmental conditions that may alter the energy cost of movement. Second, not all MET values in the Compendium of Physical Activities were derived from indirect calorimetry, and some were estimated from activities having similar movement patterns; thus some values are much less precise than others. Third, MET values in the Compendium were often estimated from a few studies based on limited individuals that potentially are less than generalizable, and do not differ either spatially or temporally. Finally, we note that the intensity values in the Compendium were derived from data gathered in high-income countries, and these intensities may differ widely from the true values in China. Thus while the MET values that we have assigned to various activities may either over- or under-report the true energy cost of that activity we have no way of testing this as there is no similarly designed reference specific to China. However, despite its limitations, energy cost data is of limited availability, and the Compendium is a useful source for applying intensity measures in the absence of measured intensity. Further, the MET approach remains the best available way to systematically apply energy cost estimates in self-report measures, particularly when activities are aggregated in questionnaires as is often the case.

An additional limitation is in the definition of community as the relevant area that defines an individual's occupational activity environment. Communities, defined as villages and townships within rural counties and urban and suburban neighborhoods within the cities, were sampled from the capital city of the province and a lower-income smaller city as well as from four economically diverse rural counties (one low-, two middle-, and one high-income).

The occupational environment may be quite heterogeneous within a community, and may differ depending on its size and whether one lives on the outskirts or within the community center. Thus, while a potentially better measure would be the more immediate surrounding area which encompasses an individual's direct occupational opportunity, we do not know the distance an individual commutes to work and have no way to calculate this. We further note that our use of the larger area with increased heterogeneity is the more conservative method given it would serve to reduce our ability to detect an ecological effect.

Finally, because we did not fully address endogeneity in this research, our ability to infer a causal relationship in longitudinal models is limited. Endogeneity can arise as a result of unobserved heterogeneity due to unmeasured or poorly measured independent variables. For instance, there may be unmeasured factors that lead individuals to either engage or not engage in physical activity (or to select a certain type of job) that also potentially affect weight status. This is possibly what is behind our failure to find an effect in longitudinal change models in the third aim where we found one in cross-sectional models. However, while occupational opportunity is increasing in China, it is still fairly limited and jobs have tended to be more circumstantial with less mobility and job choice, which may make this slightly less of a problem when studying a country such as China. Endogeneity can also arise due to reverse causality, or when the outcome also predicts the exposure. Such effects can introduce a correlation between the exposure and the error term, thus causing the model to not be strictly exogenous. Further, unobserved heterogeneity in the outcome variable could arise due to variables not properly controlled for in analyses. Fixed effects models can control endogeneity to some extent (that arising from time-invariant factors), however fixed effects models only take into account within-person variation while random effects models encompass both within- and between-individual variation. Despite their ability to provide a more exogenous model, because our interest was in assessing the total effect, we selected the random effects specification as our final model.

Despite the limitations addressed above, this research has numerous strengths. While there has been increased interest in research examining the effect that environmental factors have on physical activity behaviors of late, ours is the first study that we know of that examines the independent effect of urbanization on occupational activity in a rapidly-transitioning society. Our use of the multidimensional urbancity index allowed for a more nuanced delineation of this effect, and our employment of the multilevel model allowed us separate the community effects for the individual effects.

The longitudinal nature of the data was another major strength. Using multiple waves of data enabled us not only to test for time-dependent influences of urbanization on occupational activity and influences of activity on weight status, but it also allowed us to control to some extent for unobserved, time-varying variables, and to increase the precision of our analyses.

To our knowledge there have been no other studies which have empirically demonstrated the effect of ownership of multiple types of labor-saving household devices on weight status, independent of socioeconomic factors. Acquisition of technology is an important consequence of urbanization, and we feel that our finding of an independent effect of ownership of these devices is a potentially important contribution to the literature. Nonetheless, we must remember our use of income as a controlling variable provides a different dimension of economic well-being than wealth, which is a measure of long-term income and is more easily measured than income. Thus, it is possible that our analysis suffers from residual confounding.

A final strength of this research is our inclusion of multiple domains of physical activity; domestic activity has been particularly understudied. Many studies focus on only one type of activity, however this does not provide a complete measure of overall activity and, more importantly, may not capture the most relevant forms of activity for the specific population. For instance, much of the daily activity for Chinese adults occurs through work, and had we neglected to study occupational activity, we would have missed a very important relationship between it and weight status. Furthermore, we were able to assess energy expenditure from in depth data on intensity (in occupation), frequency, and duration. Our detailed measure allowed us to account for multiple occupation types, those that occurred in the more traditional market sphere as well as those that took place at home in gardening, livestock, running a small home business, or similar wage-earning pursuits. We found this assessment to be particularly important for women, who more frequently engage in multiple types of part-time work in both the market and domestic spheres than do men.

C. Public Health Significance

1. Our findings provide important insights regarding the effect of urbanization on adult physical activity patterns and weight status

Chinese society has undergone drastic economic development and urbanization during the years of the survey, resulting in a social transformation extending into many aspects of life for the population. The urban population is growing and previously rural areas are gradually abandoning agriculture as a way of life in favor of rural industries, necessitating significant structural transitions in employment and altering the occupational landscape. The introduction of industrialization and mechanization in the form of labor-saving devices in the home and workplace has the potential not only to free up more leisure time but also to reduce the amount of time necessary for and energy expended in previously strenuous tasks. These lifestyle changes due to urbanization potentially underlie a portion of the remarkable rise in the numbers of overweight and obese seen over the same time period, yet remain for the most part unstudied.

Our findings that the urbanicity of one's community has an independent effect on the intensity of occupational physical activity patterns is the first such study to our knowledge that has examined the effect of urbanization on physical activity. Given that occupational physical activity contributes the largest portion to total physical activity in Chinese adults, and that there is no foreseeable decline in urbanization in the future, these results herald a dramatic decline in overall occupational activity, and potentially overall physical activity for the adult populace.

Further to this, our finding that ownership of labor-saving household devices has a significant effect on the body weight of adults is an important piece of evidence that urbanization can impact the overweight status of the population. For most of the population, these appliances have been made much more available in the recent past due to increased access to technology. While overall ownership is higher in the urban than the rural areas, the rates of acquisition in the rural areas now exceeds that in the urban areas, indicating that the ability for ownership is becoming more equitable.

2. Our findings indicate that domestic physical activity is an important component of

overall physical activity

Despite evidence in the literature that domestic physical activity is an important source of overall physical activity that should not be neglected, it remains relatively understudied in comparison to other domains of activity. Our findings show that there have been continued declines in the amount of time spent (and thus energy expended) on domestic tasks for both men and women over the years of the survey. While women are more likely than men to participate in domestic activities, interestingly we found that domestic activity has a greater impact on weight status in men. There is limited literature on the characteristics of men that do domestic activity in developing countries, although in China it has been noted that those who do tend to be older and live in families that don't have multiple female members. For our sample, we did not have information on extended family structure; however, we found that men who do domestic tasks are older, more rural, have higher incomes and are more educated, and spend less time in occupational work. Our findings of an inverse effect of domestic activity on weight in men and women, although not statistically significant in women, suggests that assessment of activity from this domain is important in this population and possibly in other transitioning populations, and should not be neglected in future studies.

3. Our findings suggest that transportation and leisure time physical activity are not rapidly changing sources of activity in this population

For two survey years, 1997 and 2000, transportation and leisure time physical activity were captured in the CHNS for adults. Over this three-year period, we found very small increases in the mean amount of energy expended in these domains for both men and women, between 0.1 and 1.5 MET-hours/week. Leisure time activity is quite uncommon. In fact, in 1997 only 5.6% and 3.4% of men and women respectively reported any leisure time activity. By survey year 2000 these numbers grew by only 1.4% and 1.0% for men and women respectively. While participation has increased, evidence thus far suggests that leisure time activity is not growing in such a way, and impacts too few individuals, to be a reasonable endpoint for interventions intent on increasing total activity. Rather, public health officials and policy makers in China concerned with weight gain might more successfully focus on encouraging more "incidental" activity in order to offset reductions in other domains of activity, or focus on reducing energy intake. Regarding active commuting (transportation physical activity), while ownership of a car or motorcycle has risen from 18% to 26% between 1997 and 2000 (cars account for less than 5% of this number), it is still relatively rare, and the majority of adults continue to commute on foot or by bicycle. Although China is currently constructing a national highway system to connect major cities, with the exception of major metropolitan areas, roads within cities are still for the most part poorly maintained and very few can handle large volumes of traffic. However, as China continues to urbanize and develop further transportation infrastructure in the form of paved, well-maintained roads, highways, and public transportation systems, and as private vehicle ownership continues to rise, we expect that physical activity from this domain will also begin to shift.

4. Our findings have important policy implications for the future health of the populace

Our findings have shown how energy expenditure from occupational and domestic sources is declining within the adult population, and that both these domains are importantly associated with weight status. China's transition to a more urbanized and technological society is likely to also impact transportation physical activity in the future. If current trends continue, without substitutions of alternative forms of energy expenditure, we should expect further increases in the numbers of overweight and obese individuals. We have found that young workers are often the most sedentary. This is understandable since the types of jobs that thrive in an urbanizing environment are often more technology-driven and tend to draw a younger workforce. As young people enter the workforce in the future their first jobs are more likely to be sedentary, their home lives will similarly be less active, resulting in a freeing up of more disposable leisure time.

Future policy responses should address mechanisms that compensate for increasing sedentariness in occupational and domestic life. From a public health standpoint it seems important that as this transition continues, the populace should be encouraged and advised to use the advent of more leisure time to engage in active pursuits. Further, policy makers can use findings from studies done in the developed world which indicate that incorporating "incidental" or "lifestyle" physical activity into the fabric of an individual's life may be the most beneficial way of ensuring an adequate amount of physical activity. As individuals in China live in increasingly technology-dependent environments, findings from this study suggest that those involved in public health promotion efforts, urban planning, and transportation science need to target alternative forms of physical activity in efforts to prevent and control a widespread obesity epidemic and benefit the health of one of the largest populations on earth.

D. Directions for future research

There are a number of ways in which this research could be continued in order to advance our understanding of the effects of urbanization on activity and weight status. An important area for future research lies in additional studies utilizing the urbanization measure, particularly in analyses with other domains of physical activity. Studies investigating the etiological effects of urbanization on health status are still limited in number; yet this is an important area of research for countries undergoing the nutrition transition. Another important area for future research would be to extend analyses of the effects of urbanization to children and adolescents. It is quite easy to imagine urbanization affecting the activity patterns and overweight status of these groups, potentially resulting in effects that may last a lifetime.

We would also like to see future analyses of the effects of leisure time and transportation physical activity on weight status using subsequent waves of the CHNS. While we have no direct evidence that that patterns of leisure time and transportation physical activity will shift in the coming years, we expect to see such changes as China continues to urbanize and as adults find themselves with not only more disposable leisure time but also with increased access to public and private motorized transportation.

Finally, not only is active leisure time important, but so is leisure time spent in sedentary pursuits such as television watching and computer usage. Television ownership is already high in both urban and rural areas, and western-style satellite programming is becoming more widespread. Additionally, internet cafes and home computers are becoming more prevalent, and United States-based massive online gaming communities are finding new markets in China. For this research we did not have access to sedentary activity variables, but subsequent waves of the CHNS have and will continue to capture this important data which has been linked to overweight and obesity in diverse populations.

In conclusion, the numbers of overweight and obese in China have reached the level at which it is now a significant public health concern. Chinese society cannot be expected to revert to its traditional way of life associated with labor-intense occupations, high levels of active commuting, and diets based heavily on grains and vegetables; instead, urbanization and modernization must push forward for economic development. The relationships underlying urbanization, physical activity, and overweight are complex, but our research has provided important insights from which future analyses can be based and future insights can be made so that major population-level public health efforts can be initiated in attempts to prevent and control a widespread obesity epidemic.

Appendix: Model specifications used in cross-sectional and longitudinal analyses from Chapter VI

Model	Type of model	Outcome variable	Exposure variable
1	Logistic cross-sectional	Overweight status 1997	Continuous total MET-hrs/wk 1997
2			Categorical total MET-hrs/wk 1997
3			Continuous occupational, domestic, transportation, leisure MET-hrs/wk 1997
4			Categorical occupational, domestic, transportation, leisure MET-hrs/wk 1997
5		Overweight status 2000	Continuous total MET-hrs/wk 2000
6			Categorical total MET-hrs/wk 2000
7			Continuous occupational, domestic, transportation, leisure MET-hrs/wk 2000
8			Categorical occupational, domestic, transportation, leisure MET-hrs/wk 2000
9	Linear longitudinal	Δ BMI 1997-2000	Continuous Δ total MET-hrs/wk 1997-2000
10			Categorical quantile Δ total MET-hrs/wk 1997-2000 (one level)
11			Categorical quantile Δ total MET-hrs/wk 1997-2000 (three levels)
12			Continuous Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000
13			Categorical Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000 (one level)
14			Categorical Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000 (two levels)
15	Multinomial logistic longitudinal	Weight change category*	Categorical quantile Δ total MET-hrs/wk 1997-2000 (one level)
16			Categorical quantile Δ total MET-hrs/wk 1997-2000 (three levels)
17			Categorical Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000 (one level)
18			Categorical Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000 (two levels)
19			Top/bottom 10% of distribution in Δ total MET-hrs/wk 1997-2000
20			Top/bottom 5% of distribution in Δ total MET-hrs/wk 1997-2000
21			Top/bottom 10% of distribution in Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000
22			Top/bottom 5% of distribution in Δ occupational, domestic, transportation, leisure MET-hrs/wk 1997-2000
23			Top/bottom 10% of distribution in Δ sedentary/moderate/vigorous occupational hrs/wk

Continued

Model	Type of model	Outcome variable	Exposure variable
24	Multinomial logistic longitudinal (continued)		Top/bottom 5% of distribution in Δ sedentary/moderate/vigorous occupational hrs/wk
25			Categorical baseline quantiles of total MET-hrs/wk
26			Categorical baseline occupational, domestic, transportation, leisure MET-hrs/wk
27			Top/bottom 10% of baseline distribution total MET-hrs/wk
28			Top/bottom 5% of baseline distribution total MET-hrs/wk
29			Top/bottom 10% of baseline distribution occupational, domestic, transportation, leisure MET-hrs/wk
30			Top/bottom 5% of baseline distribution occupational, domestic, transportation, leisure MET-hrs/wk
31	Logistic longitudinal	Overweight status 2000	Categorical baseline quantiles of total MET-hrs/wk
32			Categorical baseline occupational, domestic, transportation, leisure MET-hrs/wk
33			Top/bottom 10% of baseline distribution total MET-hrs/wk
34			Top/bottom 5% of baseline distribution total MET-hrs/wk
35			Top/bottom 10% of baseline distribution occupational, domestic, transportation, leisure MET-hrs/wk
36			Top/bottom 5% of baseline distribution occupational, domestic, transportation, leisure MET-hrs/wk
37			Categorical baseline sedentary occupational hrs/wk
38			Categorical baseline vigorous occupational hrs/wk

*3-level outcome: weight maintainers, weight gainers, weight losers

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