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Individual, family, and area predictors of BMI and BMI change in an adult Norwegian population: Findings from the HUNT study

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Abstract

The global obesity epidemic is a major public health concern and there is strong evidence that the drivers are varied and operate via diverse pathways. Taking a systems approach allows the contextual influences operating upon the individual to be identified and quantified. We adopt such a perspective in this study, where longitudinal data from a cohort of 24,966 settled individuals participating in two major health surveys, the Nord-Trøndelag Health Study (HUNT 1 and 2) in the county of Nord-Trøndelag, Norway, were used to investigate associations between individual, family and area characteristics and two outcomes: body mass index (BMI) at follow-up and BMI change over an 11 year period. Linear multilevel models were fitted, with individuals nested in 17,500 families, 447 wards and 24 municipalities. A range of putative individual, family, and area predictors were tested. We found both outcomes were strongly associated with individual characteristics, with higher BMIs generally being amongst males, unmarried participants, non-smokers, those of lower education and those undertaking physically demanding work but participating in less physical activity outside work. The characteristics of those in the sample exhibiting higher BMI gain were rather similar except that women gained more and those with no employment income gained less. Contextual influences were also found to be important; although just 1 % of the unexplained variance was located on the neighbourhood and municipality levels respectively, and hence suggesting small environmental influences, between 10-13 % could be attributed to families, highlighting the importance of the familial contextual environment. Rather little is known about the manner by which family influences may operate on bodyweight hence further work is needed to understand likely mechanisms and guide future interventions.

Introduction

The increasing prevalence of obesity has been described as an epidemic process (James, 2008) and is now a major driver behind rises in the prevalence of certain chronic diseases and disabilities worldwide. Recent projections from the World Health Organisation (WHO) estimate that globally 1.6 billion adults were overweight and at least 400 million were obese in 2005, with these figures expected to grow to 2.3 billion and 700 million by 2015 (WHO, 2006). In Europe current trends are expected to give rise to 150 million obese adults by 2010 (Branca, Nikogosian, & Lobstein, 2007). The annual rate of increase in childhood obesity in

this region is a particular cause for concern, with the current prevalence being over 10 times higher than in 1970 and with 15 million children expected to be obese by 2015 (Branca et al., 2007). Indeed, some have forecasted that youths of today may, on average, live less healthy and possibly even shorter lives than their parents (Olshansky, Passaro, Hershow, Layden, Carnes, Brody et al., 2005).

In a recent WHO publication, Branca et al. (2007, p.xiii) state that “obesity presents Europe with an unprecedented public health challenge that has been underestimated, poorly assessed and not fully accepted as a strategic governmental problem with substantial economic implications”. The authors further note that the prevention of obesity requires innovative environmental approaches. The term “obesogenic environment” refers to the role environmental factors may play in determining food intake and physical activity, both important determinants of bodyweight (Jones, Bentham, Foster, Hillsdon, & Panter, 2007). Swinburn and colleagues have defined the concept as “the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals or populations” (Swinburn, Egger, & Raza, 1999 p 564). These authors have further described the environment in terms of micro and macro components, where micro-environments are defined as settings that influence peoples’ interactions (e.g. home, school, workplace, and neighbourhood) which are themselves influenced by macro-environments (e.g. the education and health system, government policy and society’s attitudes and beliefs).

The concept of an obesogenic environment is grounded in a systems perspective where health related behaviour is contextualised in the environment within which it takes place. The advancement of the concept has been driven by the development of ecological models which suggest that weight related behaviours, such as food intake and physical activity, arise as the result of the combined action of psychosocial, demographic, as well as physical environmental processes (Diez Roux, 2007; Van Dyck, Deforche, Cardon, & De Bourdeaudhuij, 2009)

Numerous different environmental factors at various geographical scales have been put forward as potential determinants of overweight and obesity (Black & Macinko, 2008). There is some evidence of an effect of income inequality, with Pickett and colleagues (Pickett, Kelly, Brunner, Lobstein, & Wilkinson, 2005) finding a positive association between income inequality and rates of obesity in 21 developed countries, whilst Holtgrave & Crosby (2006) found higher levels of social capital in US states to be associated with a lower prevalence of obesity. At the neighbourhood level, many studies in the US (e.g. Diez-Roux, Link, & Northridge, 2000; Janssen, Boyce, Simpson, & Pickett, 2006; Rundle, Field, Park, Freeman, Weiss, & Neckerman, 2008), UK (e.g. Moon, Quarendon, Barnard, Twigg, & Blyth, 2007) and in Canada (e.g. Ross, Tremblay, Khan, Crouse, Tremblay, & Berthelot, 2007) have reported that high material deprivation levels are associated with elevated adult obesity prevalence.

A large amount of research evidence on the role of the physical environment is available. A recent review of predominantly US studies found that the majority reported an association between some aspect of the neighbourhood built environment and obesity, with associations with features such as the walkability of neighbourhoods and the accessibility of greenspaces being found (Papapoulos, Alberg, Ewing, Helzlouer, Gary, & Klassen, 2007). In addition to objectively measured features, the findings of a recent meta-analysis support the view that perceptions of the neighbourhood environment, such as those regarding safety and the accessibility of destinations, are also important (Duncan, Spence, & Mummery, 2005).

A contextual unit rarely acknowledged in the obesity literature is the family or household. Yet here is compelling evidence in support of interventions at the parent or family level in

paediatric obesity research (Zeller, Reiter-Purtill, Modi, Gutzwiller, Vannatta, & Davies, 2007). Parental obesity has a strong predictive power in the development of child and adolescent obesity, arguably with a genetic component, but there are also studies suggesting that there are indeed modifiable determinants operating at this contextual level (Krahnstoever Davison, Francis, & Birch, 2005). These could include the availability of foods, and the provision of familial social support for physical activity, and weight management practices. There is strong evidence that the drivers of the epidemic are varied and operate via diverse pathways. Systems approaches (see Bailey, 1994) to exploring health behaviour causation can be useful in such situations, as they allow the outcomes of individual actions to be examined within the social and environmental contexts within which the individual operates. We adopt such a perspective in this study, where the aim is to contribute to an understanding of how environments may directly and indirectly affect behaviour and how such behaviour is ultimately expressed in terms of bodyweight. This is done firstly by quantifying variation in body mass index (BMI) and changes in BMI associated with individual, family, and area characteristics. Secondly we try to explain how the composition of individuals in families and areas may account for this variation. Finally we test how contextual features like family and area socioeconomic status, and area deprivation and social capital may explain variability in the outcomes not associated with characteristics of individuals. The research is longitudinal, utilising anthropometric height and weight measurements from two time points amongst a large and settled adult population from the county of Nord-Trøndelag in Norway.

Methods

Data sources

The Nord-Trøndelag Health Study (HUNT) is one of the world's largest population health surveys. The first wave (HUNT 1) was carried out in 1984–1986. All residents of Nord-Trøndelag County in Norway aged 20 or above were invited to participate in the study which included a physical examination and self-completed questionnaires. Questionnaire 1 was attached to the invitation letter, and 74,977 (88.1%) of the 85,100 eligible persons completed and returned it when they attended. Of these, 74,332 (99.1%) had reliable height and weight measurements recorded with light clothes and without shoes by specially trained nurses. During the clinical investigation, participants were given a second questionnaire to complete and return by mail. This collected information on socio-demographic and behavioural issues (education, alcohol intake, smoking, lifestyle issues, and functional impairment) and was returned by 53,016 (70.7%) of the study members. More detailed descriptions of the methods in HUNT 1 are provided elsewhere (Holmen, Midthjell, Bjartveit, Hjort, Lund-Larsen, Moum et al., 1990).

The second wave of HUNT (HUNT 2) was carried out in the same geographic region as HUNT 1 in the period 1995 to 1997 (Holmen, Midthjell, Krüger, Langhammer, Lingaas Holmen, Bratberg et al., 2003). Similar methods for measuring height and weight were used. A total of 47,048 (72%) of the participants in HUNT 2 had also participated in HUNT 1. Data linkage between HUNT 1 and HUNT 2 was undertaken via the national Norwegian 11 digit unique personal identification number. This number was also used to link every individual to National statistics' registries from which we derived information on place of residence (ward number), family identification number, education and income data. These registries do not however, contain information on the entire follow-up period, but only for the four years preceding the second wave of HUNT. The exception is education for which there is information dating back to 1970. All data linkages were undertaken by a third party and preserved participant anonymity. The Norwegian Data Inspectorate and the Regional Committee for Ethics in Medical Research approved the protocols for HUNT 1 and HUNT

2. The protocol for this study was approved by the Regional Committee for Ethics in Medical Research and the HUNT Publication Review Board approved the manuscript.

The present study includes men and women 25-64 years old at baseline (HUNT 1) and who participated in HUNT 2 eleven years later. Of the 47,048 participants attending both waves 24,966 were eligible for inclusion here. After excluding 7,605 individuals who were outside the age-range 25-64 years and 853 (2%) with missing weight or height measurements from any of the two waves we were left with 38,590 individuals. From these we excluded 9,447 individuals who had missing values on any of the covariates from the baseline survey (24%). In addition we left out 4,152 individuals (11%) who had changed municipality of residence between the waves (or changed ward number or family number in the period 1992 to 1995) and 25 individuals (~ 0.1%) who had an error in municipality and ward coding. Norwegian municipalities are administrative units with an average population in 1998 of 10,155. Wards are a lower level statistical unit nested within the municipalities, with an average of 322 inhabitants in 1998. The analysed subsample of 24,966 individuals constitutes 65% of the original eligible cohort. The main reason for missing values on the covariates is because of nonresponse to the second questionnaire in the baseline survey (HUNT 1) which was to be completed and returned by mail after the clinical examination. The 24,966 individuals were located in 17,500 families (Mean=1.4), 447 wards (Mean=55.9) and 24 municipalities (Mean=1040.3) respectively. Of the 17 500 families just 0.2% were three-person, 42.2% were two-person and the rest were singleton clusters (57.6%) in our data, although other family members may have been present but did not participate in HUNT.

Outcome

We fitted two sets of models; one examining BMI at the end of the follow-up in 1995, and one BMI change in the period 1984 to 1995. We calculated BMI as the ratio between body weight in kilograms (kg) and body height in meters (m) squared (kg/m^2). BMI is accepted by the WHO as the appropriate measure of assessing under- and overweight (WHO 1995). BMI-change in the follow-up period was modelled using the methodology of Vickers & Altman, (2001) by fitting BMI in 1995 as the outcome and adjusting for baseline BMI by including it as an explanatory variable in the model. This is the equivalent to the analysis of a change score.

Individual level explanatory variables

All individual level explanatory variables are baseline characteristics collected in 1984-85 (HUNT 1). Age in years and age-squared were modelled as continuous variables with both centred on their mean. Sex was modelled as a dummy variable with males as the reference category. Marital status was classified into four groups: Married (reference category), not married, widow(er), and divorced/separated. Occupational class was based on self reported responses about occupation and was classified into non-manual (reference), manual and a no-employment-income group. Education was derived from national statistics registries' and was the highest level of education achieved up until the first wave in 1984-85 (HUNT 1). We dichotomized this variable into high (completed a college or university degree) and low (primary or high school) education, with the former as reference category.

Estimates of physical activity level during work, including domestic activity amongst homemakers, were made based on responses to the question "Is your work physically demanding to the extent that you feel physically tired or exhausted at the end of the work day?" We reclassified the responses into 'yes' ("almost always" and "quite often") or 'no' ("rarely" and "seldom, hardly ever") with the latter as the reference category. Physical activity in leisure time was based on the questionnaire item: "How frequently do you exercise (give an average)? By exercise we mean, for example, going for walks, skiing,

swimming or training/sport". We dichotomized the five category response into 'inactive' (never, less than once a week, once a week) and 'active' (2-3 times a week, nearly every day) with the former as reference category. Smoking was coded as either non (reference) or current smoker.

Contextual explanatory variables

Family income was based on the aggregation of individual level data (net income) derived from Statistics Norway registries' for the two years (1993 and 94) prior to the second wave of HUNT. We calculated the average for these two years for every individual, aggregated these averages to the family level using the family identification number, and using the methodology of recent OECD publications on income inequality (OECD, 2009) we divided by the square root of the number of family members (also derived from Statistics Norway registries data) to account for scale advantages in larger families. We then calculated the natural logarithm (Ln) of this measure of "equivalent family income". Family income, an indicator of family socioeconomic status (SES), is hypothesised to relate to BMI by describing microenvironments that may be more or less conducive to physical activity and healthy eating via mechanisms of ability to pay, and also in terms of knowledge (Giskes, van Lenthe, Kamphuis, Huisman, Brug, & Mackenbach 2009; Burke, Beilin & Dunbar 2001).

Ward education level, the only available indicator of ward socioeconomic status (SES) was measured as the proportion of individuals aged between 16 and 66 with a high level of education (college or university degree) in the wards. These ecological data were derived from a secondary data source: "Censuses on constituency level" maintained by Norwegian Social Science Data Services (NSD, 2008) for the year 1990. The rationale for including this predictor is previous studies showing that neighbourhoods with a high socioeconomic status have lower levels of obesity. Access to resources conducive to physical activity and healthy eating are likely mechanisms. In addition, neighbourhood SES may act as a surrogate measure for safety, as well as the presence of chronic neighbourhood stressors, (Mujahid, Diez-Roux, Shen, Gowda, Sánchez, Shea et al., 2008).

The municipality deprivation score employed was a summary measure developed by Statistics Norway that characterised the 24 municipalities in Nord-Trøndelag County in terms of material deprivation, or "level of living" in a Norwegian context, for the year 1989 (Tønseth, 1999). The variable is a composite of the following indicators: male unemployment rate, low educational level, general practitioners per 1000 inhabitants, physiotherapists per 1000 inhabitants, average income per inhabitant, person-years in home nursing care per 10 000 inhabitants, net-migration, supplementary benefit recipients per 1000 inhabitants, prevalence of disability pension claimants, percentage child care coverage, after-school care facility provision, traffic accidents per 1000 inhabitants, male mortality 45-66 years, female mortality 45-66 years, and municipality gross income per inhabitant. The index ranges theoretically from 16 (high deprivation) to 60 (low deprivation). The indicator of population change, a longitudinal indicator for area deprivation, was similarly derived from Statistics Norway and measures percentage population change between 1984 and 1995. Previous studies have shown that place deprivation is associated with obesity, and a number of mechanisms and pathways may be operating. These include the lack of infrastructure for physical activity or healthy eating, but also the presence of health damaging factors such as outlets providing energy dense food (Macdonald, Cummins & Macintyre 2007). Social capital was measured in terms of election participation and was the pooled participation rate for the local political elections for the years 1983, 1987 and 1991. Election participation has been used as a measure of social capital in a number of previous studies (e.g. Sundquist & Yang, 2007). Likely mechanisms by which social capital could operate include the diffusion of knowledge about healthy lifestyles, maintenance of healthy norms through informal social control, promotion of access to services and amenities, and

also psychosocial processes which may, for example, act to support physical activity behaviours (Kawachi & Berkman 2000). All municipality level variables were gathered from the Norwegian Social Science Data Services who administer Statistics Norway's data for researchers.

Statistical Analyses

Multilevel linear models (Goldstein, 2003; Hox, 2002; Rabe-Hesketh & Skrondal, 2008; Snijders & Bosker, 1999) were estimated to distinguish the individual, family, ward, and municipality-level sources of variation in BMI and BMI change. The multilevel statistical modeling framework allows the simultaneous examination of the effects of group-level and individual level predictors and it accounts for the non-independence of observations (clustering) within higher level units. In addition, both inter-individual (difference between individuals) and intergroup variation (differences between higher level units) can be examined as well as the contributions of individual level and group-level variables to these variations.

In the context of the analysis presented here, the multilevel techniques allowed estimation of the overall relationships between BMI and BMI change and both individual and contextual correlates, along with the variation between the higher level units (family, ward, municipality) that could not be accounted for by these factors. The substantive and technical relevance of multilevel models in public health is well described (Blakely & Subramanian, 2006; Congdon, Shouls, & Curtis, 1997; Diez Roux, 1998, 2000, 2004a, b; Moon, Subramanian, Jones, Duncan, & Twigg, 2005; Subramanian, Jones, & Duncan, 2003).

Four-level models were estimated, with the continuous responses, of BMI and BMI change for individuals (level 1) nested within families (level 2), wards (level 3) and municipalities (level 4). The model parameters were estimated using the maximum likelihood-based Iterative Generalized Least Squares (IGLS) algorithm and the models were fitted using the MLwiN v.2.11 package (Rasbash, Charlton, Browne, Healy, & Cameron, 2009). A modeling strategy was developed whereby a null (empty) model depicting the variation in outcome between the four levels were initially fitted (Model 1). This was followed by the introduction of individual level demographic (e.g. age and sex) predictors (Model 2), then individual socioeconomic variables (e.g. education and occupation) in Model 3, then individual behavioral variables (e.g. physical activity and smoking) in Model 4, followed finally by the contextual predictors (Model 5). Using standard convention, we divide the models into fixed effects (predictor variables, the effect of which does not vary between individuals, families, wards, and municipalities) and random effects (the variance in outcome at each of these levels that remains after controlling for the fixed effects). We report these random effects in terms of the intraclass correlation coefficient (ICC) for the higher level variances. The ICC is the percentage of the total unexplained variance that is attributable to each level in the model. Likelihood ratio tests were used to determine the statistical significance of the ICCs (see Rasbash, Steele, Browne & Goldstein 2009).

Results

Table 1 describes the characteristics of the sample and the contextual variables. Mean BMI increased by nearly 2 kg/m² during the 11 years of follow-up, and the standard deviation increased from 3.47 to 3.92. Mean age at baseline was 43 years. Males and females are equally represented and the majority were married. The variables measuring individual SES indicate that most individuals reported working in manual occupations and had a low educational level. Nevertheless, the majority did not report being physically tired or exhausted at the end of the working day. A third of the individuals were physically active in their leisure time, and a similar fraction were daily smokers.

Compared to those excluded from the analyses because of missing information on the covariates, the included sample were younger, (43 vs. 46 years, $p < 0.05$), more likely be male, (50 vs. 41 percent, $p < 0.05$), to be married (84 vs. 80 percent, $p < 0.05$) to have a high education (14 vs. 8 percent, $p < 0.05$), to be employed in a non-manual occupation (21 vs. 14 percent, $p < 0.05$) and to be physically inactive (69 vs. 64 percent, $p < 0.05$). There was no difference in terms of smoking status or in reporting physically demanding work. Included women had a slightly lower BMI than excluded women in both HUNT 1 (24.3 vs. 25.1 kg/m², $p < 0.05$) and HUNT 2 (26.6 vs. 27.2 kg/m², $p < 0.05$), whereas included men also had a slightly lower BMI than excluded men in both HUNT 1 (25.2 vs. 25.4 kg/m², $p < 0.05$) and HUNT 2 (26.8 vs. 26.9 kg/m², $p < 0.05$).

Table 2 reports the unstandardised coefficients and ICC values from the models of BMI at the end of the study regressed on explanatory variables from baseline. Model 1, the null model, shows that about 83 % of the variation in BMI was at the individual level, 15 % between families and 1.24 % and 0.67 % between wards and municipalities respectively. Adjusting for sample demographics (Model 2) showed a quadratic association with age, whereby BMI was highest in middle age and lower amongst younger and older study participants. Incorporating the SES-variables (Model 3) showed higher BMI amongst respondents reporting no employment income. For the effect of education, a significant interaction with sex was present; men with a low level of education had on average a higher (0.299 kg/m²) BMI than men with high education, with a greater effect for women, whereby those with a low education had a 0.937 kg/m² (0.299 + 0.638) higher BMI than their more highly educated counterparts.

In Model 4 the addition of the behavioural variables showed that smokers and those reporting being physically active during leisure time had lower BMI whereas reporting of physically demanding work was associated with higher BMIs. Model 5, after full adjustment for contextual variables, showed no association with family income but BMIs of participants were gradually lower amongst those living in wards with more educated populations. None of the municipality level variables reached statistical significance. Compared to the null model, the proportions of variance in BMI at the municipality, ward, and family levels were somewhat attenuated after full adjustment, but all remained statistically significant.

In Table 3 we present the models examining change in BMI during the 11 year follow-up and the modelling structure is the same as that of Table 2. Model 1 shows that 89% of the variance in BMI change was at the individual level, with approximately 8%, 1% and 2.5% associated with family, ward, and municipality levels respectively. The addition of demographic variables showed a quadratic relationship with age, that BMI gain in general was greatest in females, and in widows. The inclusion of SES measures (Model 3) showed higher gains amongst those with no employment income. Educational effects for men were small, but for women low education was associated with higher BMI change. Model 4 shows that those with physically demanding jobs gained more weight whilst physical activity outside work and smoking showed no associations with BMI change. The fully adjusted model showed no effect of family income, ward level of high education or any of the municipality level variables. After adjustment of these factors the ICCs for all four levels were relatively unchanged and still statistically significant.

In order to test for any moderating effects of area type we also performed sub-group analyses by stratifying the total sample according to degree of urbanisation in the municipality (urban versus rural). The models, not reproduced for the sake of brevity, were very similar to those presented for the whole sample. One exception was in the relationship between BMI and marital status, whereby in the urban sample the divorced/separated group had a lower BMI (0.524 kg/m², $p < 0.05$) than the married group, whilst divorced/separated

participants in the rural sample had a higher BMI (0.472 kg/m^2), although this was not statistically significant. A further difference was that BMI change was associated with ward level SES in the urban sample only, with increasing SES being associated with a lower level of BMI increase (0.008 kg/m^2 less per unit increase in SES, $p < 0.05$) in this group.

Discussion

In this study we have examined the correlates of BMI and BMI change in a large longitudinal sample of adult individuals. We found that both outcomes were associated with individual characteristics, with higher BMI most often found amongst males, unmarried participants, non-smokers, those of lower education and those undertaking physically demanding work but participating in less physical activity outside work. The characteristics of those in the sample exhibiting higher BMI gain were rather similar except that women gained more and those with no employment income gained less.

The counter-intuitive finding, that those who reported physically demanding work gained more weight than those who did not, is not easily interpreted as we adjusted for a large number of confounders. It may be that this association is due to lower leisure-time physical activity along with less favourable eating habits outside the workplace for manual workers. As others have noted, it is also possible that relative weight gain is due to increased muscle mass for those reporting physically demanding work (Gutiérrez-Fisac, Guallar-Castillón, Díez-Gañán, García, Banegas, & Artalejo, 2002).

While previous studies have reported rather consistent and inverse associations between BMI change and both occupation (Martikainen & Marmot, 1999) and education (McLaren, 2007), we found modest relationships for BMI change. Taken together SES variables may relate to BMI and BMI change in different ways, where education is important in terms of knowledge of nutrition and exercise whilst occupation may have consequences for energy expenditure during the work day. Income may have an impact in terms of costs for healthy food and exercise opportunities. These associations are also likely to vary according to age, as well as between cohorts over time. In addition, as others have suggested, the SES-BMI pathway may be different for men and women and also dependent on childhood circumstances (Baltrus, Everson-Rose, Lynch, Raghunathan, & Kaplan, 2007). In this respect our results are generally consistent with previous reviews that have reported the strongest association with education, and an effect that is stronger for women (Sobal & Stunkard 1989, Ball & Crawford 2005, McLaren 2007).

Although we only had information on one member of almost 60% of families in our sample, the fact that the sample size was large, and therefore had good power, meant that we were able to examine the effects of family, something which is rarely possible. Although family income was not associated with either outcome, we did find that between 10-15% of the unexplained variance was at the family level, suggesting that some unmeasured characteristics of families may be important. The fact that BMI is correlated within families suggests the presence of a complex interplay between a possible genetic susceptibility to weight gain and characteristics of the family environment such as shared eating and physical activity habits.

The random variance in both outcomes at both the ward and municipality levels was small but statistically significant, and of a similar magnitude that found in other studies (e.g. Lebel, Pampalon, Hamel & Therieult, 2009). The fact that the variability associated with the municipality level is larger for BMI change than for BMI is interesting, and worthy of further investigation. It suggests that some characteristics of either the social or physical environment of areas may be particularly important in driving the trends in weight gain, and

also that previous cross sectional studies using a single time point may have underestimated the magnitude of environmental influences behind increasing obesity rates. Furthermore, none of the municipality-level explanatory variables were significantly associated with our two BMI outcomes. Previous studies have reported significant associations with both deprivation indices (van Lenthe & Mackenbach, 2002) and area social capital (Veenstra, Luginaah, Wakefield, Birch, Eyles, & Elliott, 2005). However, the low number of municipalities in our study (N=24) does make it difficult to establish significant associations which may require large variation in exposure.

The neighbourhood SES variable (high educational level in the wards) was associated with BMI in the total sample and with BMI change in our urban subsample in the stratified analysis. These associations may be related to norms and practices around both diet and exercise in these neighbourhoods and may be viewed as components of collective lifestyles (Frohlich, Corin, & Potvin, 2001). These are not merely the behaviours individuals engage in, but also concern the relationship between individuals' social conditions and their social practices and they hence may vary according to different neighbourhood socioeconomic context.

Families, neighbourhoods and municipalities are not fixed quantities with enduring characteristics, but are dynamic settings or systems. To some extent our study has met recent calls to utilize a "relational" perspective in area effects studies (Cummins, Curtis, Diez-Roux, & Macintyre, 2007). A relational perspective means firstly the abandonment of the context – composition dichotomy, and favours a systems view. It also clearly recognizes the importance of scale or multiple levels. We have nevertheless still used the concepts of context and composition in order to be able to make a distinction between obesity-related determinants within and outside the individual here.

In the modelling of BMI and BMI change we followed a conventional approach by first fitting a variance component model and then adding individual level variables incrementally. This allows us to adjust the models for the composition of higher level units in order to assess the remaining variation between them. Like any other observational study these are difficult issues and separating context from composition is a vexing specification problem. On the one hand there is a risk of omitting important covariates or confounders. On the other, one may over-fit the models and include mediating covariates that are on the causal pathway between the contextual exposure and the outcome. Since primary key interest here was the ecological explanatory variables (and variances) we tested different versions of compositional adjustments (results not shown). It can be argued that the behavioural characteristics in model 5 may be mediating variables rather than confounders. This is especially true for physical activity in leisure time because we implicitly assume an indirect ecological effect (Blakely & Woodward, 2000) via obesity related behaviour on BMI. The conclusions regarding the fixed higher-level effects, and the higher level variances, will however remain the same regardless of model preference.

Our study has a number of strengths and weaknesses. Strengths include the availability of data from a large, well characterized cohort of individuals. We used anthropometric height and weight measurements to calculate BMI which is preferable. The large sample size meant we had the power to examine the effects of family, ward, and municipalities and by correct assignment of individuals to these various contextual units both in time and space, we were able to achieve a stable contextual exposure through eleven years. Other researchers have noted how it is important to recognise the various levels in a population, and the exclusion of one level will affect the estimates (variance components) at other levels (Tranmer & Steel, 2001).

In terms of weaknesses, our family and ward level consists of data for the period 1992 to 1995 and not for the entire follow-up period; hence there is a possibility of incorrect assignment of individuals into these units where individuals have moved within municipalities or where family circumstances have changed. The characteristics of our sample are also less varied than the broader Norwegian population. In particular, the cohort is drawn from a single county and hence the heterogeneity in the physical environment is rather limited, which might explain our lack of findings regarding area effects. Furthermore, the study area has a very equal income distribution, even in an egalitarian Norwegian context (Elstad, Dahl, & Hofoss, 2005). It is also noteworthy that our exclusion criteria meant that a substantial proportion of the total HUNT cohort did not form part of our analysis. Although a comparison of included and excluded individuals did not reveal strong differences, those included tended to be younger, male, with a high education, and in a non manual occupation. Included individuals also had a lower BMI than their excluded counterparts. These differences may affect the generalisability of our findings. We excluded individuals who changed their area of residence in order to provide a stable sample for estimating area effects, although movers are in themselves an interesting group as they allow the effects of change in context to be examined. Whilst beyond the scope of this article, we are currently analysing change amongst this group.

Conclusion

In conclusion, we found that a statistically significant proportion of the variance in BMI and BMI change can be attributed to families, in addition to the individual. We were able to quantify the family components that determined our outcomes but insight from elsewhere does suggest that processes governing physical activity and nutrition in families are extremely complex (Kegler, Escoffery, Alcantara, Ballard, & Glanz, 2008). The small amounts of variance attributable to the ward and municipality levels show that features of the wider social and physical environment are likely to be important, yet relatively minor determinants of BMI in our study. This may in part be due to features of the Scandinavian welfare model, both in terms of social security arrangements and regional policy, which act to prevent strong geographical inequalities in health, although the magnitude of our findings is similar to that for others. There is thus a need for more research to examine both more specific pathways between contextual environments and bodyweight (Stafford, Cummins, Ellaway, Sacker, Wiggins, & Macintyre, 2007) in different macrosettings characterized by different institutional arrangements.

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Table 1

Sample characteristics

Individual level (N=24 966)	Mean	SD
Body Mass Index (BMI) 1984	24.79	3.47
Body Mass Index (BMI) 1995	26.70	3.92
Age (years)	43.1	10.8
Sex	<i>N</i>	<i>%</i>
Males (ref)	12,569	50.3
Females	12,397	49.7
Marital status		
Married (ref)	20,905	83.7
Not married	2,811	11.3
Divorced/Separated	717	2.9
Widow (-er)	533	2.1
Occupation		
Non-manual (ref)	5,302	21.2
Manual	18,348	73.5
No employment income	1,316	5.3
Education		
High (ref)	3,358	13.5
Low	21,608	86.5
Physically demanding work		
No (ref)	12,556	50.3
Yes	12,410	49.7
Physical activity (leisure time)		
Inactive (ref)	17,321	69.4
Active	7,645	30.6
Current smoker		
No (ref)	16,335	65.4
Yes	8,631	34.6
Contextual levels	Mean	SD
Family variables (N=17500)		
Income (Ln) (Kroner per annum)	10.13	3.69
Ward variables (N=447)		
High education level 1990 (%)	11.07	6.88
Municipality variables (N=24)		
Deprivation index 1989 (score)	36.54	4.44
Population change 1984-95 (%)	-4.02	7.66
Election participation pr 1000 (1983-91)	712.92	48.46

Table 2

The predictors of BMI in the sample

	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed Effects					
Individual level (intercept)	26.851	26.879	26.560	26.858	26.826
Demography					
Age (years)		0.240 **	0.257 **	0.252 **	0.253 **
Age (years) ²		-0.002 **	-0.002 **	-0.002 **	-0.002 **
Female (yes/no)		-0.086	-0.745 **	-0.906 **	-0.911 **
Not married (yes/no)		0.208 *	0.208 *	0.229 **	0.227 **
Widow (yes/no)		0.079	0.027	0.093	0.097
Divorced/Separated (yes/no)		-0.396 **	-0.430 **	-0.280	-0.265
SES					
Manual employment (yes/no)			0.044	-0.014	-0.048
No employment income (yes/no)			1.004 **	0.969 **	0.914 **
Low education (yes/no)			0.299 **	0.309 **	0.268 *
Female*low education (interaction)			0.638 **	0.817 **	0.834 **
Behaviour					
Physically demanding work (yes/no)				0.303 **	0.288 **
Active in leisure time (yes/no)				-0.491 **	-0.482 **
Current smoker (yes/no)				-0.853 **	-0.850 **
Family level					
Family income, Kroner per annum (Ln)					0.002
Ward level					
High educational level 1990 (%)					-0.026 **
Municipality					
Deprivation index 1989 (score)					0.032
Population change 1984-95 (%)					-0.018
Election participation per 1000 1983-91					-0.002
Random Effects					
Variance components[#]					
Municipality level	0.103 (0.043)	0.109 (0.045)	0.106 (0.043)	0.095 (0.039)	0.080 (0.034)
ICC (%)	0.67	0.72	0.71	0.65	0.55
Ward level	0.191 (0.035)	0.186 (0.034)	0.154 (0.031)	0.126 (0.028)	0.090 (0.025)
ICC (%)	1.24	1.23	1.03	0.86	0.61
Family level	2.377 (0.175)	2.069 (0.171)	1.994 (0.171)	1.911 (0.168)	1.927 (0.168)
ICC (%)	15.45	13.72	13.34	12.99	13.14
Individual level	12.717 (0.193)	12.720 (0.192)	12.695 (0.192)	12.580 (0.192)	12.568 (0.190)
ICC (%)	82.64	84.33	84.92	85.51	85.70

	Model 1	Model 2	Model 3	Model 4	Model 5
-2*loglikelihood:	138667.178	138198.204	138011.517	137656.051	137621.214

*
p<0.05,

**
p<0.01,

All higher level variances are significant at a 0.01 probability level (likelihood ratio test).

ICC = Intraclass correlation coefficient

Table 3

The predictors of BMI change in the sample

	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed Effects					
Individual level (intercept)	26.714	26.381	26.455	26.444	26.447
Baseline BMI	0.953 **	0.997 **	0.997 **	0.996 **	0.996 **
Demography					
Age (years)		0.050 **	0.048 **	0.048 **	0.048 **
Age (years) ²		-0.001 **	-0.001 **	-0.001 **	-0.001 **
Female (yes/no)		0.683 **	0.433 **	0.409 **	0.407 **
Not married (yes/no)		-0.008	-0.005	-0.003	-0.001
Widow (yes/no)		0.219 *	0.214 *	0.217 *	0.223 *
Divorced/Separated (yes/no)		0.014	0.011	0.008	0.015
SES					
Manual employment (yes/no)			-0.003	-0.020	-0.024
No employment income (yes/no)			-0.201 **	-0.206 **	-0.212 **
Low education (yes/no)			-0.082	-0.103	-0.108
Female*low education (interaction)			0.313 **	0.340 **	0.343 **
Behaviour					
Physically demanding work (yes/no)				0.084 **	0.083 **
Active in leisure time (yes/no)				-0.023	-0.022
Current smoker (yes/no)				0.008	0.009
Family level					
Family income, Kroner per annum (Ln)					0.003
Ward level					
High educational level 1990 (%)					-0.003
Municipality					
Deprivation index 1989 (score)					0.028
Population change 1984-95 (%)					-0.008
Election participation per 1000 1983-91					-0.002
Random Effects					
Variance components[#]					
Municipality level	0.107 (0.035)	0.118 (0.038)	0.118 (0.038)	0.119 (0.038)	0.104 (0.034)
ICC (%)	2.38	2.80	2.81	2.83	2.48
Ward level	0.042 (0.009)	0.029 (0.007)	0.029 (0.007)	0.028 (0.007)	0.028 (0.007)
ICC (%)	0.94	0.69	0.69	0.67	0.67
Family level	0.356 (0.050)	0.440 (0.047)	0.438 (0.047)	0.437 (0.047)	0.438 (0.047)
ICC (%)	7.93	10.45	10.42	10.40	10.46
Individual level	3.984 (0.059)	3.622 (0.054)	3.619 (0.054)	3.618 (0.054)	3.618 (0.054)

	Model 1	Model 2	Model 3	Model 4	Model 5
<i>ICC (%)</i>	<i>88.75</i>	<i>86.05</i>	<i>86.08</i>	<i>86.10</i>	<i>86.39</i>
$-2 \times \log \text{likelihood}$:	107681.039	105951.556	105922.524	105911.255	105906.363

*
p<0.05,

**
p<0.01,

All higher level variances are significant at a 0.01 probability level (likelihood ratio test).

ICC = Intraclass correlation coefficient