**A multinomial model for comorbidity in England of long-standing cardiovascular disease, diabetes and obesity**

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**Abstract**

Comorbidity has been found to be significantly related to increased levels of mortality, decreased functional status and quality of life, increasing dependence on health services and an increased risk of mental and social problems. Previous research into comorbidity has mainly focused on identifying the most common groupings of illnesses found among elderly healthcare users. In contrast, this paper pools data from the Health Survey for England from 2008 to 2012 to form a representative sample of individuals in private households in England to explore the risk of comorbidity among the general population; and to take account of not only the demographic but also the socioeconomic and area-level determinants of comorbidity. Using a multinomial logistic model, this research confirms that age and gender are significant predictors of cardiovascular disease, diabetes and obesity, whether examined singly or in any comorbidity combination. Across the seven possible disease combinations, the odds ratios are lowest for those individuals with a high income (6 of 7), home-owning (5 of 7), degree educated (7 of 7) and living in the least deprived area (6 of 7), when controlling for demographic and smoking characteristics. The important influence of socioeconomic factors associated with comorbidity risk indicates that healthcare policy needs to move from a focus on age profiles to take better account of individual and local area socioeconomic circumstances.

**Keywords**: cardiovascular disease, comorbidity, diabetes, general population, obesity, socioeconomic profile

**Introduction**

Along with an increased prevalence of cardiovascular disease (CVD), diabetes and obesity as single health conditions, there is a growing body of evidence that individuals are increasingly experiencing two or more of these conditions (Sachdev et al. 2004, Valderas et al. 2009, Barnett et al. 2012, Charlton et al. 2013). Comorbidity refers to one or more chronic diseases among people with an index disease (the primary disease of interest) (Gijsen et al. 2001, Valderas et al. 2009, Congdon 2010) and is associated with increased, often fragmented healthcare needs (Barnett et al. 2012, Charlton et al. 2013). Responding to the knowledge that comorbidity significantly increases mortality rates and decreases functional status and quality of life, the study of comorbidity has increased over the last decade (Islam et al. 2014). However, this research has tended to focus on identifying the most prevalent groupings of illnesses that demonstrate comorbidity (Sachdev et al. 2004), particularly among the elderly population (Gijsen et al. 2001, Fortin et al. 2007, Marengoni et al. 2011, Carey et al. 2013, Salive 2013). Indeed, in compiling a literature review on previous research into comorbidity, it is difficult to find research that is not limited to the elderly people and does not conceptualise the need for research into comorbidity within the context of the global ageing population.

In contrast, far less well established is the socioeconomic gradient in comorbidity (Barnett et al. 2012). This is in direct contrast to research into single morbidities where research over the last two decades has found that socioeconomic circumstances, in addition to demographic and genetic factors, are key determinants of individual health outcomes. The handful of studies that examine the role of socioeconomic status in comorbidity (see for example Kahn et al. 2008, Congdon 2010, Barnett et al. 2012, Charlton et al. 2013) have been based upon analyses of clinical records, GP, community care and hospital data. However, data based on clinical records are a source of revealed need: only individuals who have actively sought medical attention, usually in the 12month time period before, are included in these data sets. This overlooks those individuals with comorbidities who have not sought medical attention. Research into health service access has found a variety of reasons why individuals do not access health services even when they are ill, many closely linked to an individual’s socioeconomic circumstances, such as cost, opportunity, cost of time spent away from work or the home, distance and lack of transport (Joseph & Phillips 1984, McLafferty 2003, Wan et al. 2012). Arguably, it may be that the characteristics and life circumstances of individuals who are ill and have not sought medical attention are of most interest to public health research and healthcare provision (Kavanagh et al. 2010, Wan et al. 2012). As such, a better understanding of the epidemiology of comorbidity in the general population is necessary to develop interventions to prevent it, reduce its burden and align healthcare services more closely with patients’ needs.

Set against this backdrop, the aims of this paper were twofold. First, this paper aims to estimate the odds ratios of CVD, diabetes and obesity, both as single and comorbidities in the private household population across England. Second, this paper seeks to identify the individual-level and area-level risk factors which shape this risk, taking account of not only age and sex but also socioeconomic, lifestyle and area-level contextual factors. To achieve these goals, the paper makes use of a nationally representative sample of the private household population, the Health Survey for England (HSE).

**Methods**

*Health Survey for England*

The HSE has been carried out annually since 1995 and provides health, demographic, socioeconomic and lifestyle information at the individual level. The survey is designed to represent the population living in private households, and thus it excludes those living in institutions. Acik-Toprak (2012) highlighted that omitting institutional residents leads to underestimates of the extent of poor health in the total population, as the unhealthiest, who are over-represented in institutions – e.g. residential care homes – are excluded. However, this paper is specifically interested in exploring the prevalence of comorbidity, alongside the associated risk factors, for members of the private household population. The nature of comorbidity among this population is not well understood. For example, there is likely a mismatch between this population’s actual health needs and those revealed via contact with medical services. In contrast, those with comorbidity residing in residential homes or care facilities already have their health needs met and clinical data on their comorbidities already exist.

The HSE samples were drawn using a multistage stratified probability sampling design. Initially, a random sample of primary sampling units (PSUs), based on postcode sectors, was selected. Within each selected PSU, a random sample of postal addresses (known as delivery points) was then drawn. In single dwelling and unit household addresses, the corresponding household was selected, whereas in multi-occupied addresses, one household was selected at random. Finally, for each household, face-to-face interviews were conducted with all adults in the household and a limit of two was placed on the number of children aged 0–15 selected for interview. The final number of adult respondents for the HSE was approximately 15,000 in 2008, 4500 in 2009 and 8500 each year since 2010. The survey contains interviewer weights, which adjust for selection, non-response, and population age/sex and strategic health authority profile, the latter using estimates from the Office of National Statistics. Further details can be found in the Methods and Documentation yearly volumes associated with the survey data (e.g. Craig & Mindell 2012). Unless indicated otherwise, the analysis performed in this paper uses the HSE interviewer weights.

*Data*

In order to study the comorbidity of CVD, diabetes and obesity in adults (age 16 years and above), data from 2008 to 2012 were pooled. The HSE categorises the ailments of those respondents reporting at least one long-standing illness using the International Classification of Diseases (ICD 10). Each year all respondents, including those not reporting a current longstanding illness, are also asked whether they have ever suffered from particular health conditions, and which of these, if any, were doctor-diagnosed. The set of health conditions probed in this way is very limited and changes from year to year. Consequently, the HSE provides data on diabetes and CVD every year for those reporting a long-standing illness, but data on doctor-diagnosed CVD only for particular non-consecutive years. The need to pool data across consecutive years to generate a large enough sample of individuals with comorbidity to achieve statistical power meant that doctor-diagnosed CVD was not appropriate for this analysis.

Out of the weighted pooled total of 45,265 adult HSE participants, only 28 (0.06%) failed to give a valid response to the long-standing illness question, and therefore lacked any information on their current ailments. Dropping in addition those without a valid response to all of the variables of interest for this study (obesity and equivalised income being the most problematic) reduced the final weighted sample used within this paper by one-third (32.5%), to 30,545. From the descriptive statistics presented in Table 1, it can be seen that the age–sex distribution of HSE respondents is maintained after the removal of cases with non-response. Table 2 offers an overview of the 40 diseases into which the HSE classifies long-standing illnesses, and provides confirmation that removing cases with non-response also has minimal impact on their observed prevalence. For the impact on other study variables, see the Results section.

For the purpose of this study, individuals are categorised as having CVD if the long-standing illnesses they reported were classified into any of the follow-

ing ICD 10 categories: (i) Stroke/cerebral haemorrhage/cerebral thrombosis, (ii) Heart attack/angina, (iii) Hypertension and (iv) Other heart problems. The diabetes variable was taken directly from the survey. No differentiation between the two types of diabetes is possible from 2011 onwards because of changing patterns in the prescription of insulin therapy at early ages (which was used in previous years to determine the diabetes type). As is typical in studies using the HSE data set, obesity was approximated using the weight and height measurements provided by the HSE interviewers to compute a body mass index (BMI) measure. Using the current definition of obesity, individuals with a BMI above or equal to 30 kg/ m2 were defined as obese for the purpose of this paper. The impact of using a BMI-based measure of obesity, particularly as it relates to different ethnic groups, is further considered in the Discussion section.

With regard to the explanatory variables used in this analysis, the demographic variables included age (four categories), sex, ethnicity and marital status. The socioeconomic variables included equivalised income (by tertiles), third-level education (whether an individual has a degree or not) and tenure (using the available levels in the HSE). In similar fashion to Barnett et al. (2012), the Index of Multiple Deprivation for England (Index for Multiple Deprivation 2010) was included as a five-category variable to control for area-level deprivation. Finally, smoking was included as a lifestyle variable. Other lifestyle variables associated with CVD, diabetes and obesity include alcohol consumption, diet and exercise (Kavanagh et al. 2010). However, the HSE does not include data on physical activity and includes a question on food and diet that relates only to consumption on the previous day. Drinking frequency and quantity estimates are available in the HSE, but initial analysis found that these variables were highly correlated with age. Therefore, no variable relating to drinking behaviour was included in the model. As this paper used secondary analysis of previously collected data, ethics approval was not required.

*Statistical model: multinomial logistic regression*

Using variables that have been found to be significantly associated with each of the three morbidities, this paper uses a multinomial log-linear model to model the demographic and socioeconomic determinants of comorbidity (CVD, diabetes and obesity) at the individual level for England. Multinomial log-linear models are used when the dependent variable to be explained is polytomous and categorical, i.e. it has more than two categories with no global order between them (Morgan & Teachman 1988). Comorbidity is studied using a response variable y with eight categories, corresponding to the product of all possible combinations of CVD, diabetes and obesity status for the considered long-standing illness population; concisely: non-obese, non-CVD, non-diabetic (y = 1); obese, non-CVD, non-diabetic (y = 2); CVD, non-obese, non-diabetic (y = 3); diabetic, non-obese, non-CVD (y = 4); obese, CVD, non-diabetic (y = 5);obese, diabetic, non-CVD (y = 6); CVD, diabetic, nonobese (y = 7); obese, CVD, diabetic (y = 8).

Nnet within the R software (Venables & Ripley, 2002) is a statistical package that supports the fitting of multinomial log-linear models. Its function ‘multinom’ (Venables & Ripley, 2002) was used to fit the described model for different tested sets of explanatory variables and categorisations of those variables. All ageand sex-related interactions were considered. Only two interactions were found to be statistically significant, and neither added materially to model interpretation, so for the sake of simplicity they were discarded. The final model selected was the one with the set of regressors with the best Akaike information criterion, thus giving the best compromise between goodness of fit and complexity (Burnham & Anderson 2004).

**Results**

*The long-standing illness HSE sample*

The individual-level demographic and socioeconomic characteristics of all pooled HSE respondents are compared in Table 3 with the characteristics of those retained in our final cleaned sample of persons with no missing data. It can be observed that the two samples are closely consistent, the main difference of note being a slight under-representation of those aged 75+ (8.9% vs. 6.9%), and a slight tendency for the cleaned sample to over-represent the more affluent (e.g. 59% vs. 55% in work).

*The prevalence of comorbidity*

Table 4 presents the comorbidity profile by age and by age/gender observed in the cleaned HSE weighted sample. In general, morbidity and comorbidity rates are marginally higher for men than for women. The main exception is obesity, which is more common among women than men. There are also clear age patterns. CVD prevalence among the private household population (on its own or as part of a comorbidity) increases continuously with age for both sexes, reaching around 35% among those aged 75+. Diabetes prevalence also increases continuously with age for women, affecting 10% of those aged 75+, but for men peaks at around 13% in the age range 65–74. Obesity is far more common than either CVD or diabetes in younger ages, but its prevalence falls slightly in the oldest age groups, having peaked at around 33% for men aged 55–64 and women aged 65–74. Patterns of disease combination also vary. Obesity is more common as a stand-alone morbidity than as part of a comorbidity set, for all persons except men aged 75+. Conversely, diabetes is more commonly found in tandem with CVD or obesity than on its own at all ages, as is CVD until ages 75+. The most common comorbidity is CVD and obesity, peaking at 10% among those aged 75+. For individuals aged 75+, the rarest type of comorbidity involves all three health conditions.

For younger age groups, however, the combination of CVD and diabetes alone is rarer. If obesity leads to later onset diabetes and/or CVD, then the results in Table 4 suggest that a key health policy intervention should be to seek to reduce high levels of early-life obesity. There is also scope to assess the extent to which the prevalence of private household (co)morbidity revealed through health service usage matches that recorded in the HSE, in order to ensure that adequate health services exist to provide the complex care required to enable older comorbid patients to remain living at home. Finally, due account should be taken of the way in which the various (co)morbidities peak by age and sex.

*Multinomial logistic analysis*

Table 5 continues the analysis of the demographic and socioeconomic determinants of comorbidity by presenting the results of the multinomial model. For all combinations of (co)morbidity, the lowest risk is associated with the reference group (female, age 16– 54, white, single, high income, with a degree, owning their own home, living in the least deprived areas and currently a regular smoker). Of the health outcomes considered, CVD–diabetes has the lowest reference group risk relative to healthy persons (individuals with neither obesity, nor CVD or diabetes as long-standing illness), while single morbidity obesity has the highest risk relative to healthy persons.

Table 5 confirms the gender patterns observed in Table 4. Namely, the risk of suffering from obesity only is higher for women than for men, relative to healthy persons, whereas the risk for all other single morbidities and comorbidities is significantly higher for men than for women. The relationship between age and (co)morbidity is more complex. The odds ratios increase with age for single CVD (OR = 5.41, 7.06, 11.22) and diabetes (OR = 2.68, 4.30, 5.76), relative to healthy persons. These findings coincide with existing 2012 clinical-based estimates on CVD and related risk factor estimates, which report an age gradient for CVD and diabetes and similar gender differentials on the considered single morbidities (British Heart Foundation 2014). For single obesity [OR = 1.29, 1.21, 0.85 (not significant)], the story is more complex, with the odds ratio highest for the age category 55–64 but falling thereafter, such that those in the oldest age category (75+) actually have a lower risk than that observed for the reference age category of 16–54, having controlled for other demographic and socioeconomic factors. This result may be due to a combination of one or more of three possible causes. First, the oldest individuals within the group may have lower rates of obesity due to a cohort effect, whereby less sedentary lifestyles and lower levels of high fat, high sugar processed foods throughout the life-course of oldest people in this sample lower their risk of obesity. Second, differential survival rates due to obesity lowering life expectancy may mean a small group of individuals being obese at age 75 or above (Foresight 2007). Third, as this paper is examining private households only, there may be an effect of transfer to care homes, with the obese being more likely to be selected for transfer. This complexity in the agerelated risk of single morbidities is echoed in the agerelated risks of comorbidity. For example, for the comorbidity of obesity–diabetes (OR = 4.19, 4.01,

3.18), the age-related trends for obesity and diabetes pull in opposite directions, with the impact of obesity ultimately appearing to outweigh that of diabetes. In contrast, for the comorbidity of CVD–diabetes, risk increases straightforwardly with age (OR = 4.36, 8.48, 15.32), consistent with the fact that both single morbidities ‘pull’ in the same direction.

Controlling for all other factors, ethnicity was found to be significant for five of the seven (co)morbidities. All single and comorbidities other than single morbidity CVD were significantly more likely to happen in the black population than in the predominant white population, with the highest odds ratio observed for diabetes and CVD–diabetes (OR = 2.85, 4.53). In contrast, only single morbidity diabetes and CVD–diabetes are significantly more likely to occur in the Asian population (OR = 3.33, 4.24) than in the predominant white population. This result is similar to research by Tallin et al. (2012), whose study reported diabetes to be the most prevalent in these ethnic groups. Conversely, obesity and obesity–CVD are significantly less likely to occur in the Asian population (OR = 0.61, 0.47) relative to the white population. In combination with the observed higher diabetes risk, this result points to the debate on the suitability of the current BMI threshold defining obesity for the Asian population (see e.g. James et al. 2002). The recent NICE Public Health Guidance (2013) is to use specific BMI thresholds (lower than usual) for both black and Asian ethnic groups to define obesity only for diabetes prevention, but not for the general purpose of defining obesity. However, to date, a consensus on the specific BMI thresholds to use for each ethnicity group has not yet been reached.

Turning our attention to marital status, being single was associated with a lower odds ratio than any other marital status across all morbidity combinations, controlling for the other factors in the model. Other than the reference category single, cohabitees experienced the lowest risks across all (co)morbidity types, many of which were not statistically different from the reference category. Despite having controlled for age, the highest odds ratio was experienced by the widowed for all (co)morbidity categories except single morbidity diabetes and obesity–diabetes, where the separated/divorced experienced a higher risk. Other than this, the odds ratio for those married or separated/divorced were similar to, but slightly lower than, those who were widowed. One clear point to draw from this analysis of marital status is that being single is a protector for all comorbidities. This result is a surprise given the supposed protective effect of marriage for most health outcomes (Williams 2003). It should also be noted that despite controlling for age, there is a danger that the influences of marital status and age remain partially confounded due to the wide range of the first age group (16–54), necessitated by the low numbers of the comorbid in younger ages.

Table 5 also considers the impact of a range of socioeconomic factors. Controlling for all other factors, persons in the highest income tertile experience the lowest risk across all morbidity combinations. There is also an observable income gradient for all (co)morbidities except CVD, with lower income being associated with higher odds ratios, although this gradient is only significant for obesity, and all three morbidities combined. For example, those in the middleincome tertile have an odds ratio of 1.47 for all three comorbidities; a risk which increases to 1.85 in the lowest income tertile. Other indicators of affluence display a similar gradient. Not having a degree increases the odds ratio for all disease combinations (not significant for diabetes and obesity–diabetes), while not being in work increases the risk for all but obesity. For tenure, the story is more complex, per-

haps reflecting the somewhat indirect link between income and chosen tenure category. However, home owners (the reference category) do have a lower odds ratio for all disease combinations except single morbidity CVD and diabetes, although this reduced risk is statistically significant only for obesity and for all three comorbidities.

With regard to area effects, the broad pattern is that living in more deprived lower super output areas (IMD, 2010) is associated with an increased odds ratio of (co)morbidity. The exception is that for diabetes, obesity–diabetes and CVD–diabetes, the odds ratio reduces slightly for the most deprived areas, although it still remains higher for the least deprived areas. This finding is similar to that of Charlton et al. (2013) who found a significant association between area deprivation and comorbidities in England.

Finally, we turn our attention to lifestyle. Here, the multinomial model found that, as expected, former regular smokers have a higher disease risk than non-smokers for all disease combinations. Current smokers were also found to have statistically significant lower levels of risk than those who had never smoked regularly for most disease combinations. Given the known health risks associated with smoking, this was deemed a surprising result. To examine this relationship further, a simple logistic model was run for obesity using smoking status as the independent variable and controlling for demographic factors. The logistic model showed that average BMI is lower for current smokers than for non-smokers, while BMI is highest for ex-smokers. These relationships are significant.

An increase in weight when quitting smoking has been reported elsewhere (Alley et al. 2010, Aubin et al. 2012), and we hypothesise that the decreased obesity risk for current smokers compared to exsmokers is associated with such weight gain. Finally, it should be observed that for all but one disease combination, the odds ratio for current smokers is markedly lower than for former regular smokers. Given that numerous medical studies show that quitting smoking reduces disease risk (see e.g. Clair et al. 2013 on CVD), this is hypothesised to be in part due to the weight-gain effect of quitting smoking noted above, and in part due to a selection effect, whereby smokers are more likely to become ex-smokers once they have contracted a smoking-related morbidity.

**Discussion**

Previous clinical research into comorbidity has focused mainly on identifying the most prevalent and prognostically important illnesses that tend to demonstrate comorbidity (Sachdev et al. 2004), while both clinicaland population-based research have focused on the elderly population, with age and sex viewed as the prime determinants of comorbidity. Yet, an individual’s health is known to be the outcome of multi-faceted processes and not just the result of ageing or initial health status alone (Morrissey et. al. 2013). Our analysis of persons aged 16 and over living in private households in England suggests that individualand area-level socioeconomic characteristics are also important comorbidity risk factors, just as they are already known to be for CVD, diabetes and obesity as single morbidities (Congdon 2010, Kavanagh et al. 2010, Fone et al. 2013). We argue, therefore, that increased attention needs to be paid to the influence of socioeconomic factors on comorbidity, both in England and internationally.

Other factors are also associated with comorbidity. Our analysis found that gender and marital status are significant predictors of all seven disease combinations considered (except obesity for gender). With regard to ethnicity, the black population presents a high risk for diabetes (and diabetes-related comorbidity), while the Asian population presents a high risk for diabetes but low risk for obesity. With regard to socioeconomic status, having controlled for demographic and lifestyle factors, the risk for all of the comorbidities considered was lowest for individuals with an equivalised income in the highest tertile, owning their own home, working and having a degree. Examining the area-level variable IMD, the analysis found that the most deprived areas have higher levels of morbidity and comorbidity than the least deprived areas. Having controlled for demographic characteristics, the continuing strong associations between (co)morbidity and lower individuallevel and area-level socioecomomic status reinforce the need to concentrate health promotion and health policy efforts on reducing social inequalities rather than on targeting particular age groups or behavioural characteristics alone (Kavanagh et al. 2010). The association between IMD quintile and comorbidity also suggests that health interventions need to be spatially targeted.

Following Frohlich and Potvin (2008), we note that interventions that attempt to alter some of society’s behavioural norms, for example the banning of smoking in public places, assumes that everyone’s risk exposure is reduced by the same amount, regardless of one’s initial position in the risk exposure distribution. In reality, socioeconomic position has been repeatedly shown to influence an individual’s behavioural characteristics (Frohlich & Potvin 2008, Kavanagh et al. 2010). As Frohlich and Potvin (2008) argue, the notion of vulnerable populations differs from that of populations at risk in that a population at risk is defined by a higher measured exposure to a specific risk factor. In contrast, a vulnerable population is a subpopulation which, because of shared social characteristics, is commonly exposed to contextual conditions that places it at a higher risk than the rest of the population. The findings of this paper indicate that, controlling for demographic factors, individuals in lower socioeconomic groups across England may be defined as vulnerable groups. Thus, we argue that inequalities in health outcomes are unlikely to change without attention being paid to the generators of socioeconomic inequalities. With regard to health policy, these findings indicate that solutions to redressing health inequalities may lie outside the health sector (Frohlich & Potvin 2008, Kavanagh et al. 2010), thus calling for a more interdisciplinary approach to public health provision. We further argue that a focus on vulnerable populations is a necessary complement to a population-wide approach if social inequalities in health are to be addressed.

Finally, with regard to the provision of health services, this study indicates that in England, a single disease management approach is no longer suitable for a large number of patients. As comorbidity is significantly related to increased levels of mortality and decreased functional status and quality of life, healthcare should shift its focus from specific diseases to multiple pathologies, where worsening functional status, increasing dependence of care and the increased risk of mental and social problems (Gijsen et al. 2001, Islam et al. 2014) are more acute. Furthermore, given the socioeconomic gradient observed in this paper and previous international research (Kavanagh et al. 2010), interventions to reduce comorbidities should be tailored to the unique risk profile and needs of high-risk communities (Rodriguez et al. 2013).

**Concluding comments**

While the research presented in this paper focused primarily on individual-level factors, our results indicate that having controlled for these factors, risk of (co)morbidity is still higher in more deprived areas (as measured using IMD). To explore the association between area deprivation and comorbidity, future research must include both individual and contextual environmental factors. Place of residence is strongly patterned by social position; neighbourhood characteristics may be important contributors to health disparities (Diez Roux & Mair 2010). There is a growing appreciation of the role that contextual environmental factors or ‘neighbourhood’ effects play on physical

health (Diez Roux & Mair 2010). Neighbourhoods have both physical and social attributes that may influence health. Physical attributes include access to goods and services, green space, and availability of alcohol and tobacco outlets; social attributes include community unemployment, segregation, social capital, civic participation and crime (Diez Roux & Mair 2010). Thus, the next step in our own research will be to incorporate spatial referencing within the HSE via a spatial microsimulation algorithm (Morrissey et al. 2013, Clarke et al. 2014) and the Census of Population 2011 to help understand how rates of comorbidity are represented across England. Creating a spatially representative demographic, socioeconomic and comorbidity profile for the population of England will allow identification of comorbidity hotspots in relation to current health supply facilities, highlighting areas with potential unmet health service needs (Morrissey et al. 2008).

To conclude, this paper uses pooled 2008–2012 HSE data to explore the risk of comorbidity within the wider private household population of England. The HSE is a nationally representative sample, with a wide variety of health, demographic and socioeconomic variables. Using the HSE expands previous research into comorbidity from a small subset of the population recorded through clinical records to the general population. Furthermore, the individual-level nature of the HSE data also meant that comorbidities in the same person, rather than comorbidities in sub populations, could be identified. Finally, this research is innovative in that it focuses on the demographic, socioeconomic and area-level characteristics associated with comorbidity of the full adult population (16+) of England rather than the elderly population alone. This is particularly important if public health research is to be successfully used in developing prevention initiatives for comorbidity.

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**References**

Acik-Toprak N. (2012) SARs Use Example: Comparing the Health of Elderly People in Communal Establishments and Households with the 2001 Individual Licensed SARs. CCSR, University of Manchester, England.

Alley D.E., Lloyd J. & Shardell M. (2010) Can obesity account for cross-national differences in life expectancy trends? In: E.M. Crimmins, S.H. Preston & B. Cohen (Eds) International Differences in Mortality at Older Ages: Dimensions and Sources, pp. 164–192. The National Academies

Press, Washington, DC. Aubin H.J., Farley A., Lycett D., Lahmek P. & Aveyard P. (2012) Weight gain in smokers after quitting cigarettes: meta-analysis. British Medical Journal 345, e4439.

Barnett K., Mercer S.W., Norbury M., Watt G., Wyke S. & Guthrie B. (2012) Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. Lancet 380 (9836), 37–43.

British Heart Foundation (2014) Cardiovascular Disease, Statistics. British Heart Foundation, Birmingham.

Burnham K.P. & Anderson D.R. (2004) Multimodel inference: understanding AIC and BIC in Model Selection. Sociological Methods and Research 33, 261–304.

Carey I., Shah S., Harris T., DeWilde S. & Cook D. (2013) A new simple primary care morbidity score predicted mortality and better explains between practice variations than the Charlson index. Journal of Clinical Epidemiology 66 (4), 436–444.

Charlton J., Rudisill C., Bhattarai N. & Gulliford M. (2013) Impact of deprivation on occurrence, outcomes and health care costs of people with multiple morbidity. Journal of Health Services Research and Policy 18 (4), 215–223.

Clair C., Rigotti N.A., Porneala B., Fox C.S., D’Agostino R.B., Pencina M.J. & Meigs J.B. (2013) Association of smoking cessation and weight change with cardiovascular disease among adults with and without diabetes. The Journal of the American Medical Association 309, 1014–1021.

Clarke S., Birkin M. & Heppenstall A. (2014) Sub regional estimates of morbidities in the English elderly population. Health and Place 27, 176–185.

Congdon P. (2010) A multilevel model for comorbid outcomes: obesity and diabetes in the US. International Journal of Environmental Resources and Public Health 7 (2), 333–352.

Craig R. & Mindell J. (2012) Health Survey for England 2011: Volume 2. Methods and Documentation. The Health and Social Care Information Centre, Leeds.

Diez Roux A. & Mair C. (2010) Neighborhoods and health. Annals of the New York Academy of Sciences 1186, 125–145.

Fone D., Greene G. & Farewell D. (2013) Common mental disorders, neighbourhood income inequality and income deprivation: small-area multilevel analysis. British Journal of Psychiatry 202, 286–293.

Foresight (2007) Tackling Obesities: Future Choices – Project Report. Government Office for Science, London.

Fortin M., Dubois M.F., Hudon C., Soubhi H. & Almirall J. (2007) Multimorbidity and quality of life: a closer look. Health and Quality of Life Outcomes 5, 52.

Frohlich K.L. & Potvin L. (2008) The inequality paradox: the population approach and vulnerable populations. American Journal of Public Health 98, 216–221.

Gijsen R., Hoeymans N., Schellevis F.G., Ruwaard D., Satariano W. & van den Bos G. (2001) Causes and consequences of comorbidity: a review. Journal of Clinical Epidemiology 54 (7), 661–674.

Index for Multiple Deprivation (2010) Department for Communities and Local Government, London.

Islam M.M., Valderas J.M., Yen L., Dawda P. & Jowsey T. (2014) Multimorbidity and comorbidity of chronic diseases among the senior Australians: prevalence and patterns. PLoS ONE 9 (1), e83783.

James W.P.T., Chen C. & Inoue S. (2002) Appropriate Asian body mass indices? Obesity Review 3 (3), 139.

Joseph A. & Phillips D. (1984) Accessibility and Utilization: Geographical Perspectives on Health Care Delivery. Harper & Row, London, UK.

Kahn R., Robertson R.M., Smith R. & Eddy D. (2008) The impact of prevention on reducing the burden of cardiovascular disease. Circulation 118, 576–585.

Kavanagh A., Bentley R.J., Turrell G., Shaw J., Dunstan D. & Subramanian S.V. (2010) Socioeconomic position, gender, health behaviours and biomarkers of cardiovascular disease and diabetes. Social Science & Medicine 71, 1150–1160.

Marengoni A., Angleman S., Melis R., Mangialasche F. & Karp A. (2011) Aging with multimorbidity: a systematic review of the literature. Ageing Research Reviews 10, 430–439.

McLafferty S. (2003) GIS and health care. Annual Review of Public Health 24, 25–42.

Morgan S.P. & Teachman J.D. (1988) Logistic regression: description, examples, and comparisons. Journal of Marriage and the Family 50, 929–936.

Morrissey K., Clarke G.P., Hynes S., O’Donoghue C. & Ballas B. (2008) Examining access to GP services in rural Ireland using microsimulation analysis. Area 40 (3), 354–364.

Morrissey K., O’Donoghue C., Clarke G.P. & Li J. (2013) Using simulated data to examine the determinants of acute hospital demand at the small area level. Geographical Analysis 45 (1), 49–76.

Wan N., Benjamin Zhan F., Zou B. & Gaines Wilson J. (2012) Spatial access to health care services and disparities in colorectal cancer stage at diagnosis in Texas. Professional Geographer 65 (3), 527–541.

NICE Public Health Guidance (2013) Assessing Body Mass Index and Waist Circumference Thresholds for Intervening to Prevent Ill Health and Premature Death among Adults from Black, Asian and Other Minority Ethnic Groups in the UK. NICE Public Health Guidance 46.

Rodriguez F., Wang Y., Naderi S., Johnson C. & Foody J. (2013) Community-level cardiovascular risk factors impact geographic variation in cardiovascular disease hospitalizations for women. Journal of Community Health 38, 451–457.

Sachdev M., Lena Sun J., Tsiatis A., Nelson C., Mark D. & Jollis J. (2004) The prognostic importance of comorbidity for mortality in patients with stable coronary artery disease. Journal of the American College of Cardiology 43 (4), 576–582.

Salive M. (2013) Multimorbidity in older adults. Epidemiology Reviews 35, 75–83.

Tillin T., Hughes A.D. & Godsland I.F. (2013) Insulin resistance and Truncal Obesity as Important Determinants of the Greater Incidence of Diabetes in Indian Asians and African Caribbeans Compared with Europeans: Thw Southal and Brent REvisited (SABRE) cohort. Diabetes Care 36 (2), 383–393.

Valderas J.M., Starfield B., Sibbald B., Salisbury C. & Roland M. (2009) Defining comorbidity: implications for understanding health and health services. Annals of Family Medicine 7 (4), 357–363.

Venables W.N. & Ripley B.D. (2002) Modern Applied Statistics with S, 4th edn. Springer, New York.

Williams G. (2003) The determinants of health: structure, context and agency. Sociology of Health & Illness 25 (1), 131–154.

**Table 1** The age-gender distributions of the Health Survey for England (HSE) weighted samples before removing non-response (HSE0), and after doing so (HSE sample)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sex | Male | | | |
| Age | 16-54 | 55-64 | 65-74 | 75+ |
| HSE0 (%) | 33.08 | 7.19 | 4.98 | 3.69 |
| HSE (%) | 34.25 | 7.53 | 4.99 | 3.11 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sex | Female | | | |
| Age | 16-54 | 55-64 | 65-74 | 75+ |
| Sub-sample used in paper (%) | 32.8 | 7.44 | 5.45 | 5.19 |
| All HSE respondents (%) | 33.56 | 7.57 | 5.16 | 3.84 |

**Table 2** Overview of the diseases included in the Health Survey for England (HSE) as long-standing illness estimated using the (weighted) HSE adult samples with valid response to the LSI question before removing non-response to the variables of interest (HSE0 sample) and after doing so (HSE sample)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | HSE0 Sample | | HSESample | |
| HSE illness category | % | Persons | % | Persons |
| Cancer (neoplasm) | 1.9 | 863.2 | 1.7 | 534.1 |
| Diabetes | 4.6 | 2101.4 | 4.2 | 1287.7 |
| Other endocrine/metabolic | 4.3 | 1954.5 | 4.2 | 1292.8 |
| Mental health problems/anxiety/depression/nerves (nes) | 4.1 | 1844.0 | 4.2 | 1281.7 |
| Mental handicap | 0.1 | 61.3 | 0.1 | 24.6 |
| Epilepsy/fits/convulsions | 0.8 | 347.7 | 0.7 | 209.2 |
| Migraine/headaches | 0.8 | 344.6 | 0.8 | 229.2 |
| Other problems of nervous system | 2.3 | 1051.4 | 2.1 | 651.8 |
| Cataract/poor eye sight/blindness | 1.1 | 491.0 | 0.9 | 262.6 |
| Other eye complaints | 1.0 | 447.3 | 0.9 | 290.2 |
| Poor hearing/deafness | 1.4 | 611.5 | 1.2 | 377.4 |
| Tinnitus/noises in the ear | 0.2 | 105.1 | 0.2 | 72.7 |
| Meniere’s disease/ear complaints causing balance problems | 0.3 | 130.6 | 0.3 | 86.7 |
| Other ear complaints | 0.1 | 45.6 | 0.1 | 26.5 |
| Stroke/cerebral haemorrhage/cerebral thrombosis | 0.8 | 360.6 | 0.6 | 183.3 |
| Heart attack/angina | 1.6 | 709.9 | 1.4 | 438.5 |
| Hypertension/high blood pressure/blood pressure (nes) | 6.6 | 2967.1 | 6.1 | 1850.6 |
| Other heart problems | 3.4 | 1518.0 | 3.1 | 953.9 |
| Piles/haemorrhoids including varicose veins in anus | 0.0 | 12.8 | 0.0 | 7.9 |
| Varicose veins/phlebitis in lower extremities | 0.1 | 49.4 | 0.1 | 35.5 |
| Other blood vessels/embolic | 0.9 | 387.1 | 0.8 | 233.3 |
| Bronchitis/emphysema | 0.8 | 345.0 | 0.7 | 222.1 |
| Asthma | 5.7 | 2594.0 | 5.9 | 1796.2 |
| Hay fever | 0.7 | 339.3 | 0.8 | 237.5 |
| Other respiratory complaints | 1.7 | 760.8 | 1.6 | 481.6 |
| Stomach ulcer/ulcer (nes)/abdominal hernia/rupture | 1.1 | 499.4 | 1.1 | 330.4 |
| Other digestive complaints | 1.4 | 630.0 | 1.5 | 445.6 |
| Complaints of bowel/colon | 2.1 | 941.5 | 2.1 | 645.5 |
| Complaints of teeth/mouth/tongue | 0.1 | 30.0 | 0.1 | 15.9 |
| Kidney complaints | 0.7 | 302.4 | 0.6 | 177.6 |
| Urinary tract infection | 0.1 | 28.8 | 0.1 | 16.7 |
| Other bladder problems/incontinence | 0.3 | 144.6 | 0.3 | 91.4 |
| Reproductive system disorders | 0.9 | 418.1 | 0.9 | 288.6 |
| Arthritis/rheumatism/fibrositis | 8.1 | 3652.9 | 7.6 | 2319.1 |
| Back problems/slipped disc/spine/neck | 4.8 | 2176.9 | 4.8 | 1477.6 |
| Other problems of bones/joints/muscles | 5.6 | 2526.2 | 5.1 | 1567.9 |
| Infectious and parasitic disease | 0.2 | 81.6 | 0.2 | 60.6 |
| Disorders of blood and blood-forming organs and immunity disorders | 0.8 | 355.1 | 0.8 | 233.4 |
| Skin complaints | 1.4 | 642.2 | 1.5 | 452.1 |
| Other complaints | 0.3 | 146.0 | 0.3 | 97.0 |
| Unclassifiable (no other codable complaint) | 0.8 | 384.3 | 0.8 | 245.8 |

**Table 3** Characteristics of the 2008–2012 Health Survey for England (HSE) weighted sample before removing non-response (HSE0 sample) and after doing so (HSE sample)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | HSE0 sample |  | HSE sample |  |
| Variables | Level | Persons | % | Persons | % |
| All persons |  | 45,237.5 | 100.0 | 30,545.1 | 100.0 |
| 1+ LSI |  | 18,499.6 | 40.1 | 12,238.8 | 40.1 |
| Gender | Male | 22,137.6 | 48.9 | 15,233.1 | 49.9 |
|  | Female | 23,100.0 | 51.1 | 15,312.1 | 50.1 |
| Age | 16–54 | 29,884,0 | 66.1 | 20,712.2 | 67.8 |
|  | 55–64 | 6,619.0 | 14.6 | 4610.1 | 15.1 |
|  | 65–74 | 4,718.3 | 10.4 | 3100.3 | 10.2 |
|  | 75+ | 4,016.2 | 8.9 | 2122.5 | 6.9 |
| Ethnicity | White | 39,835.8 | 88.1 | 27,583.7 | 90.3 |
|  | Black | 1,257.9 | 2.8 | 745.0 | 2.4 |
|  | Asian | 3,069.4 | 6.8 | 1660.7 | 5.4 |
|  | Other | 898.7 | 2.0 | 555.8 | 1.8 |
| Marital status | Single | 10,336.8 | 22.9 | 6392.4 | 20.9 |
|  | Married/civil partners | 22,697.4 | 50.2 | 15,868 | 51.9 |
|  | Cohabitees | 5,649.9 | 12.5 | 4159.6 | 13.6 |
|  | Separated/divorced | 3,629.4 | 8.0 | 2505.5 | 8.2 |
|  | Widowed | 2908.2 | 6.4 | 1619.6 | 5.3 |
| Index of multiple deprivation quintile | Least deprived | 9,476.4 | 20.9 | 6735.1 | 22.0 |
| Second | 9,156.5 | 20.2 | 6447.0 | 21.1 |
| Third | 9,257.5 | 20.5 | 6241.8 | 20.4 |
| Fourth | 8,918.3 | 19.7 | 5914.9 | 19.4 |
| Most deprived | 8,428.8 | 18.6 | 5206.4 | 17.0 |
| Income tertile | Lowest | 10,748.5 | 30.1 | 8895.9 | 29.1 |
|  | Medium | 12,131.3 | 33.9 | 10,424.9 | 34.1 |
|  | Highest | 12,880.9 | 36.0 | 11,224.3 | 36.7 |
| Work status | In work | 24,662.1 | 54.5 | 17,936.5 | 58.7 |
|  | Not in work | 20,377.6 | 45.0 | 12,608.7 | 41.3 |
| University | Yes | 10,188.0 | 22.5 | 7327.1 | 24.0 |
|  | No | 34,865.6 | 77.1 | 23,218.0 | 76.0 |
| Tenure | Renting or free | 14,168.4 | 31.3 | 9020.0 | 29.5 |
|  | Owning | 13,412.5 | 29.6 | 8520.8 | 27.9 |
|  | Buying or shared | 17,527.9 | 38.7 | 13,004.4 | 42.6 |
| Smoking | Never regular | 24,339.3 | 53.8 | 16,443.3 | 53.8 |
|  | Currently | 9,372.6 | 20.7 | 6446.2 | 21.1 |
|  | Former regular | 11,071.6 | 24.5 | 7655.6 | 25.1 |

*Note*: Percentages do not add up to 100 due to rounding effects

**Table 4** Prevalence (%) of obesity, cardiovascular disease (CVD), and diabetes morbidities and comorbidities by age and by age/gender group among the pooled (weighted) HSE 2008-2012 sample of England’s private household population

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sex | Age | Total (persons) | Obese only (%) | CVD only (%) | Diabetes only (%) | Obese, CVD (%) | Obese, diabetic (%) | CVD, diabetic (%) | All 3 (%) |
| All | 16-54 | 20,712.2 | 19.7 | 1.7 | 0.8 | 1.4 | 0.7 | 0.1 | 0.3 |
|  | 55-64 | 4,610.1 | 21.1 | 8.2 | 1.6 | 6.6 | 2.6 | 0.9 | 2.0 |
|  | 65-74 | 3,100.3 | 18.1 | 12.1 | 2.7 | 8.4 | 2.6 | 2.2 | 3.3 |
|  | 75+ | 2,122.5 | 13.3 | 19.8 | 3.5 | 10.0 | 2.1 | 3.5 | 1.8 |
| Male | 16-54 | 10,461.3 | 18.8 | 1.8 | 0.9 | 1.5 | 0.8 | 0.2 | 0.4 |
|  | 55-64 | 2,299.0 | 21.1 | 9.7 | 2.1 | 7.7 | 2.6 | 1.3 | 2.3 |
|  | 65-74 | 1,524.3 | 15.7 | 14.0 | 3.9 | 8.1 | 2.9 | 2.4 | 4.0 |
|  | 75+ | 948.5 | 11.8 | 20.7 | 4.3 | 9.5 | 2.2 | 4.3 | 2.0 |
| Female | 16-54 | 10,250.9 | 20.6 | 1.5 | 0.6 | 1.4 | 0.6 | 0.1 | 0.3 |
|  | 55-64 | 2,311.1 | 21.2 | 6.7 | 1.1 | 5.6 | 2.5 | 0.6 | 1.7 |
|  | 65-74 | 1,576.0 | 20.4 | 10.2 | 1.5 | 8.6 | 2.3 | 1.9 | 2.6 |
|  | 75+ | 1,174.1 | 14.5 | 19.0 | 2.9 | 10.4 | 2.1 | 2.9 | 1.7 |

**Table 5** Multinomial logistic model of comorbidity of obesity, cardiovascular disease (CVD) and diabetes among the pooled (weighted) 2008–2012 Health Survey for England sample

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Obese | CVD | Diabetic | Obese, CVD | Obese, Diabetes | CVD, diabetes | All 3 |
| Reference | 0.07\*\* | 0.01\*\* | 0.00\*\* | 0.00\*\* | 0.00\*\* | 0.00\*\* | 0.00\*\* |
| Male | 0.94 | 1.46\*\* | 1.93\*\* | 1.22\*\* | 1.46\*\* | 1.75\*\* | 1.80\*\* |
| Age 55–64 | 1.29\*\* | 5.41\*\* | 2.68\*\* | 5.13\*\* | 4.19\*\* | 4.36\*\* | 5.84\*\* |
| Age 65–74 | 1.21\*\* | 7.06\*\* | 4.30\*\* | 6.46\*\* | 4.01\*\* | 8.48\*\* | 7.33\*\* |
| Age 75+ | 0.85 | 11.22\*\* | 5.76\*\* | 7.05\*\* | 3.18\*\* | 15.32\*\* | 3.64\*\* |
| Ethnicity: Black | 1.22\* | 1.02 | 2.85\*\* | 1.29 | 1.55 | 4.53\*\* | 1.79 |
| Ethnicity: Asian | 0.61\*\* | 1.09 | 3.33\*\* | 0.47\*\* | 1.11 | 4.24\*\* | 1.02 |
| Ethnicity: other | 0.88 | 0.80 | 1.65 | 0.65 | 0.43 | 0.09 | 2.49\* |
| Married/civil partnership | 1.88\*\* | 1.93\*\* | 1.50\* | 2.84\*\* | 2.05\*\* | 1.75\* | 3.22\*\* |
| Cohabitees | 1.56\*\* | 1.35 | 1.16 | 1.36 | 1.69\* | 1.31 | 1.88 |
| Separated/divorced | 1.65\*\* | 1.74\*\* | 1.37 | 2.61\*\* | 2.78\*\* | 1.62 | 3.10\*\* |
| Widowed | 1.90\*\* | 2.42\*\* | 1.36 | 3.23\*\* | 2.31\*\* | 1.86\* | 3.99\*\* |
| Index of multiple deprivation quintile 2 | 1.16\*\* | 1.00 | 1.32 | 0.99 | 1.20 | 1.01 | 1.35 |
| Index of multiple deprivation quintile 3 | 1.20\*\* | 1.28\*\* | 1.68\*\* | 1.37\*\* | 1.05 | 1.61\* | 1.58\* |
| Index of multiple deprivation quintile 4 | 1.31\*\* | 1.28\*\* | 1.63\*\* | 1.99\*\* | 1.54\* | 1.58\* | 1.96\*\* |
| Index of multiple deprivation quintile 5 (most deprived) | 1.56\*\* | 1.36\*\* | 1.62\* | 2.04\*\* | 2.08\*\* | 1.24 | 3.21\*\* |
| Income: low | 1.33\*\* | 1.24\* | 1.32 | 1.16 | 1.49\* | 1.44 | 1.85\*\* |
| Income: medium | 1.11\*\* | 1.24\*\* | 1.12 | 0.96 | 1.24 | 1.24 | 1.47\* |
| Not in work | 0.94 | 1.44\*\* | 1.45\*\* | 1.33\*\* | 1.40\* | 1.68\*\* | 1.87\*\* |
| Education: no degree | 1.40\*\* | 1.21\* | 1.10 | 1.80\*\* | 1.19 | 1.54\* | 2.03\*\* |
| Renting or free ownership | 1.24\*\* | 0.95 | 0.81 | 1.13 | 1.33 | 1.09 | 1.87\*\* |
| Buying or 1⁄2 rent/mortgage | 1.24\*\* | 0.93 | 0.94 | 1.38\*\* | 1.17 | 1.02 | 1.40 |
| Never regular smoker | 1.31\*\* | 0.93 | 0.82 | 1.48\*\* | 1.19 | 1.16 | 1.85\*\* |
| Former regular smoke | 1.61\*\* | 1.12 | 1.33 | 2.10\*\* | 1.75\*\* | 1.29 | 3.37\*\* |

\* Significant at the 0.05 level; \*\* significant at the 0.01 level

The reference group is: female, age 16–54, white, single, high income, in work, degree, home-owning, living in the most deprived area and currently smoking.

The odds ratio coefficients of the model and their significance levels are shown