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Abstract:
We investigate the relationship between obesity and life expectancy, and whether or not this relationship varies by socioeconomic status (SES). The underlying model is based on the "Pathways to health" framework in which SES affects health by modifying the relationship between lifestyles and health. We use data from the British Health and Lifestyle Survey (1984-1985) and the longitudinal follow-up in June 2009, and run parametric Gompertz survival models to investigate the association between obesity and life expectancy, also accounting for interactions between obesity and both age and SES. Generally we find that obesity is negatively associated with survival, and that SES is positively associated with survival, in both men and women. There is no evidence of interactions between obesity and SES in predicting survival in men, but these interactions are present in women. Obesity is associated with lower survival in women except for older women in higher SES groups, who have a longer predicted survival than women of normal weight in this group.

Keywords: obesity; life expectancy; socioeconomic status; survival analysis

JEL classification: I14, I18, I19

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Sammendrag

Vi undersøker forholdet mellom fedme og levealder, og hvorvidt dette forholdet varierer med sosioøkonomisk status (SES). Den underliggende modellen er basert på et "Pathways to health" rammeverk der SES påvirker helsen ved å endre forholdet mellom livsstil og helse. Vi bruker data fra British Health and Lifestyle Survey (1984-1985) i tillegg til oppfølgings data fra juni 2009. Vi bruker parametriske Gompertz survival modeller for å undersøke sammenhengen mellom fedme og forventet levealder og interaksjoner mellom fedme, alder og SES. Vi finner at fedme er negativt assosiert med forventet levealder, og at SES er positivt assosiert med forventet levealder, for både menn og kvinner. Det er ingen bevis på at interaksjoner mellom fedme og SES påvirker forventet levealder hos menn, men disse interaksjonene er tilstede hos kvinner. Fedme er assosiert med lavere levealder hos kvinner med unntak for eldre kvinner i høyere SES grupper, som har en lengre forventet levealder enn kvinner med normal vekt i denne gruppen.

1. Introduction

Rising obesity levels are a major problem in many countries. In England in 1993 15% of adults aged 16 years and over were obese (13% of men, 16% of women); by 2010 this figure had risen to 26% (of both sexes) (National Centre for Social Research & Department of Epidemiology and Public Health (UCL), 2010). There is evidence that obesity is an important risk factor for a number of diseases including coronary heart disease, type II diabetes, hypertension and stroke (NHLBI, 1998), and that it is associated with a loss of health-related quality of life (Kinge and Morris, 2010).

There is also evidence that obesity is associated with increased risk of death and reduced life expectancy. In England 7% of all deaths are attributable to obesity (House of Commons Health Committee, 2004). A number of studies have investigated the association between obesity and mortality in the general population (see, e.g., Abell et al., 2008; Allison et al., 1999; Batty et al., 2006; Bender et al., 1998; Calle et al., 1999; Czernichow et al., 2011; Fontaine et al., 2003; Kvamme et al., 2012; Lawlor et al., 2006; Mayhew et al., 2009; Seidell et al., 1996; Tsai et al., 2006; Yan et al., 2006; Adams et al., 2006; Flegal et al., 2005; Freedman et al., 2006; Stevens et al., 1998; Al Snih et al., 2007; Vapattanawong et al., 2010). These have generally found a negative association between obesity and life expectancy, though there is some evidence that the association between obesity and life expectancy may be diminished among people at older ages (see, e.g., Al Snih et al., 2007; Bender et al., 1998; Diehr et al., 1998; Grabowski & Ellis, 2001; Stevens et al., 1998).

While the association between obesity and life expectancy has been investigated, little attention has been given to variations in this association between socioeconomic groups. Some studies have controlled for socioeconomic status (SES) (e.g., Adams et al., 2006; Al Snih et al., 2007; Batty et al., 2006; Calle et al., 1999; Czernichow et al., 2011; Freedman et al., 2006; Stevens et al., 1998; Vapattanawong et al., 2010; Yan et al., 2006), usually measured in terms of education, but we have not found any studies that analysed whether or not the impact of obesity varies by SES. This is important, however, given the interest in social inequalities in health (Marmot, 2010; CSDH, 2008).

Concerns with the interface between the determinants of health have lead to the development of a "Pathways to health" framework (Birch et al., 2000), in which health is determined by a range of factors that interact with one another but are not easily separable. This approach is based in part on Grossman's (1972) human capital model. Medical care, lifestyle, SES and other social determinants of health are inputs into the production of health that interact with one another in complex ways. SES and other social determinants of health affect health directly, but they also modify the association between medical care and lifestyles and health (Birch et al., 2000). According to this approach the health (*H*) of individual *i* depends on their medical care (*M*), genetic endowments (*E*), lifestyles (*L*) and SES (*Y*), plus an error term *u*:

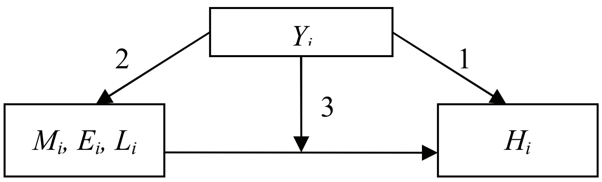
[1] $$H_i = a_0 + a_1 L_i + a_2 M_i + a_3 E_i + a_4 Y_i + a_5 L_i * Y_i + u_i$$

Lifestyles also are affected by genetic endowments and SES plus an error term *e*:

[2] $$L_i = b_0 + b_1 E_i + b_2 Y_i + e_i$$

Health in Eq.[1] also depends on the interaction between *L* and *Y*, denoted by the asterisk, illustrating that SES modifies the impact of the other factors. In this framework SES impacts health in three ways (Figure 1): it affects health directly (arrow 1); it affects healthy via its impact on lifestyles (arrow 2), which in turn affect health; and, it affects health by modifying the relationship between lifestyles and health (arrow 3).

Figure 1. Impact of SES on health using the "Pathways to health" framework



SES affects health directly as it makes individuals more efficient producers of health (Grossman, 1972). For example, education affects the ability to process information regarding health, and income affects the ability to live in less unhealthy areas. An example of how SES affects health via its impact on lifestyles is that obesity affects health and the prevalence of obesity varies by SES (McLaren, 2007). One reason for the 'modifying' role of SES is that the underlying cause of unhealthy lifestyles may affect the impact that lifestyles have on health, and these may vary by SES (Birch et al., 2000). For example, the underlying causes of obesity among those earning low incomes may be due to the consumption of cheaper less nutritional food, whereas among those earning high incomes it may be due to limited non-work leisure time making it difficult to undertake time-intensive physical activity (Butland et al., 2007). Another reason is that the strength of the association between unhealthy lifestyles and health might vary by SES (Birch et al., 2000). For example, the production relationship between obesity as an input and health as an output may vary between population groups. Hauck et al., (2002) suggest that variations in health arise *inter alia* from systematic variations in health production functions between population (e.g., socioeconomic) groups, implying that individuals with more favourable social determinants of health are likely to be more efficient in producing health.

Using this framework we are not aware of any studies that have investigated whether or not there is socioeconomic variation in the relationship between obesity and life expectancy. Hence, the aims of this study are to investigate the relationship between obesity and life expectancy, and to investigate whether or not this relationship varies by SES. We analyse data from an individual level health survey and its longitudinal follow up, which includes height and weight collected at nurse visit, plus a set of individual and household characteristics that allows us to control for confounding factors that affect the relationship between obesity and life expectancy. We use models to account for unobservable heterogeneity and test for interactions between obesity and both age and SES.

2. Methods

2.1 Data

The analysis is based on data from the first wave of the *Health and Lifestyle Survey* (HALS1) (1984/1985; *n*=9003) and the longitudinal follow up in June 2009. HALS1 surveys a representative sample of the population of Great Britain aged 18 years and over. Data for HALS1 were collected between Autumn 1984 and Summer 1985, in two home visits. At the second of these a research nurse took a range of physiological measurements including height and weight. In the longitudinal follow up in June 2009 the original participants in HALS1 were flagged on the NHS Central Register (NHSCR), a computerised record of NHS patients, routinely notified about deaths. The linkage between HALS1 and NHSCR meant that it was possible to assess whether or not participants in HALS1 had died by June 2009 and if so, their date of death. Ninety eight percent of participants in HALS1 were identified in the NHSCR.

In our analysis we excluded pregnant women at the date when body mass index (BMI) was measured and individuals with missing BMI data; this reduced the sample to 7,289 observations. We also excluded individuals under the age of 40 years at the time of HALS1, for two reasons. First, by 2009 low mortality rates were observed among those below 40 years of age, which meant that a high proportion of the survival data were censored in this group. Second, there is some uncertainty about the SES of those under 40 years of age; our SES measures are based on educational, occupation and social class, which may change over time, especially among younger groups. We are unable to account for such changes in our analysis, which means that the observed impact of SES on survival could be biased. A similar approach was used in previous analyses of HALS data (Balia & Jones, 2008). This reduced the sample to 4,062 individuals.

2.2 Variables

The dependent variable is survival time, which is measured as the time to death or censoring in months from the date at which height and weight were measured in HALS1. Thus, survival is measured from date of BMI measurement in HALS1 to either date of death or date last recorded alive (June 2009) if the respondent did not die during the follow-up period.

Our obesity measure is based on BMI, measured as weight in kilogrammes divided by height in metres squared (kg/m^2). BMI is computed from the height and weight measures obtained during the nurse visit; it is not based on self-reported height and weight, which means that the likelihood of systematic measurement error is reduced. Obesity is measured as a categorical variable based on three BMI categories: normal weight, BMI 18.5-25 kg/m^2; overweight, BMI 25-29.9 kg/m^2; and, obese, BMI $\geq$30 kg/m^2. There are a small number of respondents in the underweight category (BMI <18.5 kg/m^2; 41 men, 83 women). We do not combine underweight and normal weight because there is some evidence that the underweight have lower life expectancy than the normal weight (See, e.g., Flegal et al., 2005). We therefore include underweight as a separate category.

We use a composite measure of SES. To construct this measure we use interval regression to regress total weekly household income reported in 12 income bands (including an open-ended top category) against a set of socioeconomic variables. In the regression we include all individuals over the age of 18. The socioeconomic variables included as covariates in the regression are: education qualifications (measured in six categories); social class of household reference person (seven categories); individual economic activity status (seven categories); owning a house (yes/no); and, bedrooms in household (four categories). We calculate predicted values from this model and use these predictions as our measure of SES. We use a composite measure rather than a single SES indicator in order to capture multiple dimensions of SES. To maximise the sample size, we included individuals in the survival models with missing income data for whom we could compute a predicted value, and included an indicator for missing income (yes/no), to control for the possibility that income may not be missing at random. Using this approach we compute SES values for 1,313 individuals over the age of 40 with missing income values. We use the predicted measure to create four indicators describing SES quartiles and use these in the survival models.

In the survival models we also control for a number of individual and household characteristics. Age was included as a quadratic function (based on likelihood ratio tests for functional form). We also control for smoking status (three categories) as it has been shown to modify the association between BMI and mortality (Stevens et al., 2000), marital status (five categories), geographical area (ten categories) and ethnicity (three categories). We run separate models for men and women.

2.3 Statistical methods

Data were analysed using parametric Gompertz survival models. The model was parameterised assuming an exponential increase in mortality over time *t*:

[3] $$h(t) = \exp(x\beta + \gamma t)$$

where $h(t)$ is the mortality rate at time *t*, $\lambda = \exp(x\beta)$ and γ are the scale and shape parameters of the mortality curve, and the baseline hazard $h_0(t) = \exp(\gamma t)$. We estimate four models:

[4] $$h(t) = \exp(\beta_0 + \beta_1 W + \beta_2 Y + \beta_3 A + \beta_4 X + \gamma t)$$

[5] $$h(t) = \exp(\beta_0 + \beta_1 W + \beta_2 Y + \beta_3 A + \beta_4 X + \beta_5 W * Y + \gamma t)$$

[6] $$h(t) = \exp(\beta_0 + \beta_1 W + \beta_2 Y + \beta_3 A + \beta_4 X + \beta_6 W * A + \gamma t)$$

[7] $$h(t) = \exp(\beta_0 + \beta_1 W + \beta_2 Y + \beta_3 A + \beta_4 X + \beta_5 W * Y + \beta_6 W * A + \gamma t)$$

where *W* is obesity, *Y* is SES, *A* is age, *X* are other covariates, described above, which are likely to affect mortality, and the asterisks denote interactions between variables. In Eq.[4] the association between obesity and survival is constant between SES groups. In Eq.[5] it varies between SES groups, captured by the coefficient β_5. In Eq.[6] the association between obesity and survival is constant across SES groups, but varies by age, captured by β_6, and in Eq.[7] it varies by both SES and age. We use likelihood ratio tests and Akaike's Information Criterion (AIC) to compare the fit of models with and without interaction terms.

We experimented with using Weibull, generalised gamma, Gompertz, exponential, lognormal and log-logistic paramateric survival functions, selecting the Gompertz distribution because it best fitted our data, based on plots of cumulative Cox-Snell residuals and AIC. We accounted for unobservable heterogeneity in every model using a gamma frailty distribution. To determine whether the results are sensitive to the parametric assumptions, as suggested by Newey et al. (1990), we reanalysed the data using the semi-parametric Cox proportional hazards model.

Using the results of the regression models we plotted survival curves for obesity and SES groups, and we predicted median survival for obesity groups (normal, overweight, obese), SES groups (four quartiles) and baseline ages (40, 50, and 60 years), at the mean values of the other covariates.

In all analyses *P* values below the 5% level (z scores higher than ≈1.9) are regarded as statistically significant. Values between 5% and 10% (z scores between ≈1.6 and ≈1.9) are regarded as weakly significant.

3. Results

Our estimation sample comprised 1,832 men and 2,230 women of whom 1,052 (57%) and 1,023 (46%), respectively, were deceased at the censoring point (Table 1). Comparable figures by obesity category for men were 463 of 817 (57%) in the normal weight group, 445 of 807 (55%) in the overweight group, and 107 of 167 (64%) in the obese group. For women these figures were 471 of 1,150 (41%) in the normal weight group, 335 of 687 (49%) in the overweight group, and 172 of 311 (55%) in the obese group. A higher percentage was reported deceased in lower SES quartiles compared with higher SES quartiles across every BMI group for both men and women. The mean times to censoring among those who did not die were 291.5 months 291.3 months for all men and all women, respectively. The mean unadjusted times to death among those all men and all women died were 145.1 months and 155.6 months, respectively. Values in each obesity group were similar. The mean age of all men and women in the sample was 58 years (both sexes), respectively (Appendix A). 32% of men and 28% of women were regular smokers. 97% and 98% of men and women, respectively, were in the White European ethnic group; 82% and 70%, respectively, were married, 13% and 11%, respectively, were educated to degree level, 54% and 19%, respectively, were working full time; and, 5% and 6%, respectively, were living in a household where the household reference person was in the professional social class. There was some variation in these values between obesity groups.

Table 1. Summary of data used in the survival models

	Whole sample		Normal weight		Overweight		Obese	
	Observations (%)	Failures* (%)	Observations (%)	Failures* (%)	Observations (%)	Failures* (%)	Observations (%)	Failures* (%)
Men								
All	1832 (100)	1052 (57)	817 (100)	463 (57)	807 (100)	445 (55)	167 (100)	107 (64)
SES quartile								
1 (most deprived)	427 (23)	372 (87)	196 (24)	169 (86)	168 (21)	147 (87)	44 (26)	37 (85)
2	434 (24)	310 (71)	195 (24)	131 (67)	185 (23)	132 (72)	39 (23)	32 (84)
3	446 (24)	212 (48)	170 (21)	81 (48)	220 (27)	102 (47)	53 (32)	28 (53)
4 (least deprived)	525 (29)	158 (30)	256 (31)	82 (32)	234 (29)	64 (27)	31 (19)	10 (29)
Mean time to censoring (months)**	291.5		291.5		291.6		291.1	
Mean time to death (months)***	145.1		144.4		145.7		145.2	
Women								
All	2230 (100)	1023 (46)	1150 (100)	471 (41)	687 (100)	335 (49)	311 (100)	172 (55)
SES quartile								
1 (most deprived)	589 (26)	457 (81)	262 (23)	192 (77)	202 (29)	159 (81)	98 (32)	84 (88)
2	582 (26)	305 (51)	282 (25)	144 (50)	188 (27)	92 (48)	94 (30)	56 (61)
3	568 (25)	182 (29)	309 (27)	86 (26)	170 (25)	66 (35)	73 (23)	23 (28)
4 (least deprived)	491 (22)	79 (16)	297 (26)	49 (16)	127 (18)	18 (14)	45 (14)	8 (18)
Mean time to censoring (months)**	291.3		291.3		291.3		291.3	
Mean time to death (months)***	155.6		154.8		159.6		156.0	

Notes:
The figures do not control for age at BMI measurement.
* Failures are deaths that occurred prior to the censoring point.
** Includes only individuals who had survived up until censoring.
*** Includes only individuals who died before censoring.

Education, social class of household reference person, working full time, bedrooms in household and home ownership are all positively correlated with weekly total household income (Table 2). We used these coefficients to predict income for each respondent, who were then categorised into quartiles based on the predicted income values. The range of values for predicted total weekly income was 30 to 295; the cut-points used to set the quartiles were 91, 133 and 179.

Table 2. Interval regression of weekly total household income against SES indicators

	Coef.	z
Educational qualifications		
Degree or equivalent	Base category	
Higher education below degree	-14.76	-3.3
NVQ3/GCE A Level or equivalent	0.24	0.1
NVQ2/GCE O Level or equivalent	-13.00	-3.1
Other	-31.23	-8.1
No qualification	-20.37	-3.5
Social class of household reference person		
Professional	Base category	
Managerial technical	-24.52	-4.8
Skilled non-manual	-44.59	-7.9
Skilled manual	-47.02	-8.9
Semi-skilled manual	-56.09	-9.9
Unskilled manual	-55.63	-8.1
Other	-32.91	-3.2
Economic activity status for last week		
Working full time	Base category	
Working part time	-17.40	-5.2
Unemployed	-67.74	-13.3
Permanently sick or disabled	-58.84	-8.1
Retired	-66.74	-22.3
Keeping house	-37.58	-11.4
Full time student	-52.17	-4.1
Bedrooms in household		
One	Base category	
Two	10.71	2.3
Three	25.23	5.6
Four or more	74.03	13.9
Housing tenure		
Own accommodation	35.62	14.5
Rent	Base category	
Constant	184.78	28.0
Observations	5787	
Adjusted R^2	0.08	

The results of Gompertz survival models with gamma-distributed frailty are in Table 3. The models without interaction terms show a statistically significant association between obesity and mortality: obesity is associated with a higher hazard rate in each time period compared with those in the normal weight category, conditional on the other covariates. This association is more pronounced in women than in men. These models also show a statistically significant and positive relationship between SES and mortality: higher SES groups have lower mortality in each time period compared with lower SES groups, conditional on the other covariates.

Likelihood ratio tests comparing the fit of the three models with interaction terms to the model with no interaction terms were non-significant in each case in men (all $P \geq 0.35$). None of the interaction terms is individually statistically significant. The AIC supports the model with no interaction terms in men. In women, the likelihood ratio test was statistically significant in the model with interactions between obesity and SES and obesity and age compared with the other three models (all $P \leq 0.03$), and individual interaction terms are statistically significant. The AIC also supports this model. Hence, the interactions between obesity and SES and obesity and age do not explain variation in the survival in men, but they do in women.

Table 3. Results of Gompertz survival models with gamma-distributed frailty controlling for individual and household characteristics

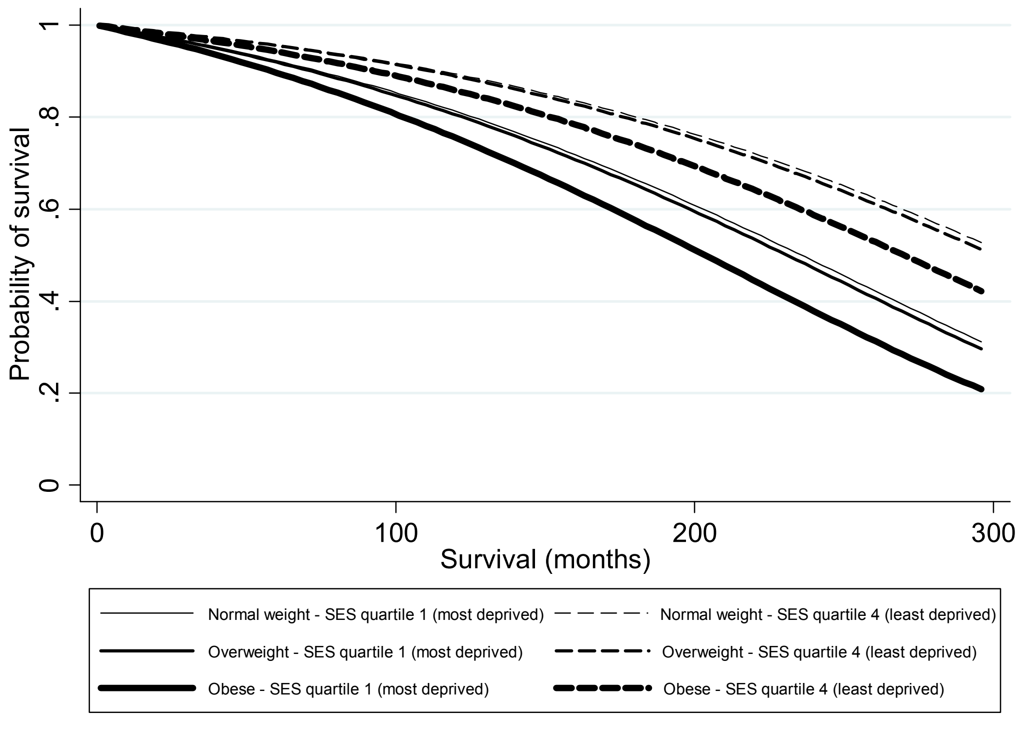
	No interactions (Eq.[4])				Interactions between obesity and SES (Eq.[5])				Interactions between obesity and age (Eq.[6])				Interactions between obesity and SES and obesity and age (Eq.[7])			
	Men		Women		Men		Women		Men		Women		Men		Women	
	Hazard ratio	z	Hazard Ratio	z	Hazard Ratio	z	Hazard ratio	z	Hazard ratio	z	Hazard ratio	Z	Hazard ratio	z	Hazard ratio	z
BMI																
Normal weight	Base category		Base category		Base category		Base category		Base category		Base category		Base category		Base category	
Overweight	1.040	0.55	0.981	0.81	1.043	0.73	1.133	1.04	0.627	-1.08	1.203	0.37	0.771	-0.49	2.293	1.44
Obese	1.342	2.59	1.420	3.46	1.261	0.23	1.595	3.09	1.386	0.45	4.334	2.53	1.568	0.52	13.496	3.65
SES quartile																
1 (most deprived)	Base category		Base category		Base category		Base category		Base category		Base category		Base category		Base category	
2	0.867	-1.69	0.889	-1.37	0.743	-2.35	1.003	0.02	0.866	-1.70	0.888	-1.43	0.739	-2.37	1.062	0.50
3	0.715	-3.26	0.773	-2.43	0.755	-1.87	0.815	-1.39	0.716	-3.24	0.783	-2.35	0.742	-1.91	0.921	-0.56
4 (least deprived)	0.566	-4.83	0.511	-4.61	0.636	-2.90	0.626	-2.57	0.566	-4.83	0.522	-4.53	0.623	-2.88	0.739	-1.62
BMI*SES																
Overweight*SES quartile 2					1.215	1.11	0.719	-1.75					1.234	1.18	0.675	-2.13
Overweight*SES quartile 3					0.920	-0.43	0.970	-0.15					0.959	-0.20	0.873	-0.63
Overweight*SES quartile 4					0.764	-1.29	0.616	-1.58					0.805	-0.96	0.533	-1.96
Obese*SES quartile 2					1.438	1.28	0.907	-0.43					1.419	1.21	0.743	-1.32
Obese*SES quartile 3					0.892	-0.38	0.727	-1.10					0.880	-0.41	0.516	-2.18
Obese*SES quartile 4					0.946	-0.14	0.661	-0.99					0.903	-0.24	0.409	-2.03
Age																
Age	1.179	5.31	1.159	4.62	1.178	5.23	1.163	4.72	1.176	5.24	1.169	4.93	1.176	5.17	1.180	5.28
Age squared	0.999	-2.25	1.000	-1.39	0.999	-2.18	1.000	-1.50	0.999	-2.28	1.000	-1.59	0.999	-2.17	1.000	-1.82
BMI*age																
Overweight*age									1.008	1.19	0.997	-0.43	1.004	0.59	0.990	-1.26
Obese*age									0.999	-0.06	0.983	-1.96	0.997	-0.27	0.969	-3.07
Observations	1832		2230		1832		2230		1832		2230		1832		2230	
Test for unobservable heterogeneity ψ	*P*=0.29		*P*=0.03		*P*=0.27		*P*=0.05		*P*=0.29		*P*=0.15		*P*=0.26		*P*=0.3	
Goodness of fit (AIC)	3306.636		3433.824		3311.97		3438.245		3309.022		3433.461		3315.417		3431.565	
LR tests																
vs. model with no interactions					*P*=0.35		*P*=0.27		*P*=0.45		*P*=0.11		*P*=0.51		*P*=0.02	
vs. model with interactions between obesity and SES													*P*=0.76		*P*<0.01	
vs. model with interactions between obesity and age													*P*=0.47		*P*=0.03	

Notes:
Controlling for smoking, ethnicity, marital status, area and missing income.
ψ *P* <0.05 shows statistically significant unobservable heterogeneity.

Analogous regression results obtained using semi-parametric Cox proportional hazards model are in Appendix B. The hazard ratios are similar in terms of their statistically significance, sign and order of magnitude.

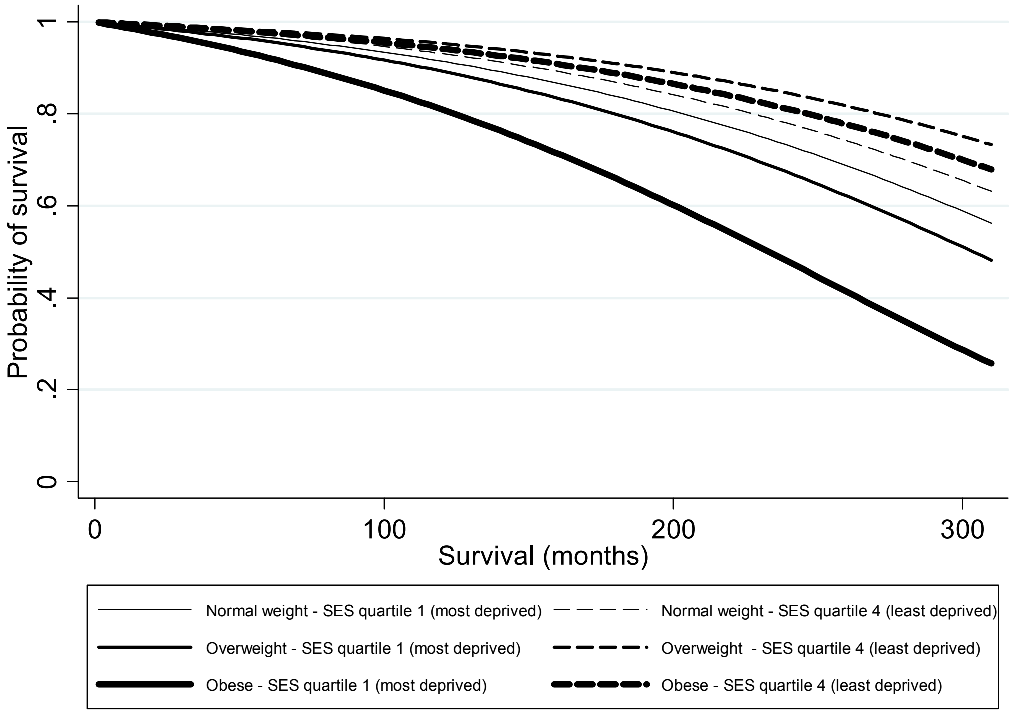
Figure 2 shows selected predicted survival curves for men based on the model with no interaction terms in Table 3. Curves are shown for SES group 1 (least deprived) and SES group 4 (most deprived) in each obesity category. Within SES groups, survival declines with obesity. Within obesity groups survival improves with SES. Survival curves for women based on the model with interactions between obesity and SES and obesity and age are in Figure 3. The trends are similar to those for men, except that in the highest SES group overweight and obese women have better survival compared with those who are normal weight.

Figure 2. Predicted survival curves for men based on Gompertz survival model with gamma-distributed frailty



Note:
The figure is derived using the regression results for the model with no interactions based on Eq.[4], shown in Table 3.

Figure 3. Predicted survival curves for women based on Gompertz survival model with gamma-distributed frailty



Note:
The figure is derived using the regression results for the model with interactions between obesity and SES and obesity and age based on Eq.[7], shown in Table 3.

Table 4 shows predicted survival in men and women stratified by age and gender. In men, predicted life expectancy declines with age, increases with SES, and declines with obesity in each SES quartile and at each age. Trends were less consistent for women, as a result of basing the predictions on the preferred regression results, including the statistically significant interaction terms between obesity and SES and obesity and age. Predicted life expectancy declines with age. It also generally increases with SES: in each age and obesity group the least deprived group has the best predicted life expectancy, and either SES quartile 1 or 2 have the worst predicted life expectancy. At younger ages, predicted life expectancy declines with obesity in each SES quartile and at each age. At older ages predicted life expectancy is higher among those in the least deprived group who are overweight and obese, compared with those who are normal weight. (Note that overall, these figures are comparable to those reported in life tables for 2008-2010 for the general population of Great Britain (Office for National Statistics (ONS), 2011); they predict residual life expectancy at age 40, 50 and 60 of 40 years, 30 years and 22 years in men and 43 years, 34 years and 25 years in women).

Table 4. Predicted median survival in years based on Gompertz survival models with gamma-distributed frailty

	Age 40			Age 50			Age 60		
	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese
Men									
All	42.5	42.1	39.4	30.4	30.0	27.4	20.2	19.8	17.5
SES									
1 (most deprived)	39.6	39.1	36.5	27.6	27.2	24.7	17.7	17.3	15.2
2	41.1	40.7	38.0	29.0	28.6	26.1	18.9	18.6	16.4
3	43.1	42.7	40.0	31.0	30.6	28.0	20.7	20.3	18.0
4 (least deprived)	45.6	45.2	42.5	33.4	33.0	30.4	22.9	22.5	20.1
Women									
All	50.6	49.0	40.8	37.2	36.6	30.9	25.2	25.7	22.3
SES									
1 (most deprived)	49.8	45.2	35.4	36.4	33.0	25.7	24.5	22.3	17.6
2	49.2	48.8	37.9	35.8	36.5	28.1	23.9	25.5	19.7
3	50.7	47.6	43.2	37.3	35.3	33.2	25.3	24.4	24.5
4 (least deprived)	53.1	55.2	48.0	39.6	42.8	37.9	27.5	31.5	29.0

Note:
The predicted medians are in years based on the survival models setting the individual and household characteristics to their whole sample mean values. The individual and household characteristics are smoking status, marital status, geographical area and ethnicity. In men the predictions are derived using the regression results for the model with no interactions based on Eq.[4], shown in Table 3. In women the predictions are derived using the regression results for the model with interactions between obesity and SES and obesity and age based on Eq.[7], shown in Table 3.

4. Discussion

The aims of this study were to investigate the relationship between obesity and life expectancy, and whether or not this relationship varied by SES. We provide evidence to show that obese men have a lower predicted life expectancy than normal weight men after controlling for a range of individual characteristics. In women we find that this relationship depends on SES and age. Obesity is associated with lower survival in women except for older women in higher SES groups, who have a longer predicted survival than women of normal weight in this group.

Mayhew et al. (2009), also using British data, calculated expected life years lost from obesity by applying hazard ratios based on Cox models for obese individuals to life tables for the general population. They found that for non-smoking men, the expected years of life lost across all ages would be 4 to 16 years for individuals with BMI in excess of 35 compared to those with a BMI of 24. For non-smoking women this was 2 to 10 years compared to having a BMI of 26. Hence, they have found a more negative effect of obesity in men. In contrast, we find a more negative effect in females, which varies by age and SES. The main differences between our studies are that we control for a wider range of covariates in our analysis, we account for unobservable heterogeneity (frailty), and we have a longer follow up period.

We also investigate the impact of overweight as well as obesity on survival; in all our models the hazard ratio for overweight is not significantly different to unity. Some studies have found evidence a negative effect of overweight on survival (see, e.g., Peeters et al., 2003; Adams et al., 2006), but others have not (see, e.g., Flegal et al., 2005). Batty et al. (2006) found an increased risk of all cause mortality in the overweight using UK data.

We find some evidence of "Pathways to health" in our results, especially for women, suggesting that the role of SES in modifying the relationship between obesity and survival. There are other examples of this finding in the case of obesity. For example, there is evidence to suggest that the impact of obesity on health status varies by SES. Laaksonen et al. (2005) show that the association between BMI and health status (measured using the physical and mental health component summaries of the SF-36, www.rand.org) is modified by occupational class and working conditions. The association between BMI and health status did not significantly change when occupational class and working conditions were controlled for; there was some evidence that the association between BMI and physical health depended on working conditions. Kinge & Morris (2010) showed that the association between obesity and health-related quality of life (measured by the EQ-5D, www.euroqol.org) varied by SES. They found significant interactions between obesity status and SES, and the association between obesity and health status was more negative in the lower SES groups than in the higher SES groups.

Outside of obesity, there is some evidence of a modifying role of social determinants of health in the context of the association between lifestyles and health. For example, Davey Smith and Shipley (1991) show that the association between smoking status and 10-year mortality risk depends on occupational grade and car ownership. Birch et al. (2000) show that the association between smoking status and self-assessed health status depends on household income, employment status and education. Pampel & Rogers (2004) show that the association between smoking and health (measured using both self-assessed health and functional limitations) was more pronounced in lower SES groups.

Our findings have implications for studies analysing the impact of obesity on health and interventions to reduce obesity, especially cost-effectiveness analyses that investigate whether or not interventions to manage obesity represent good value for money where the preference in many countries is to use quality-adjusted life expectancy when measuring outcomes (NICE, 2008). Our findings suggest that attention needs to be paid to the role of SES when undertaking such analyses, e.g., because the cost-effectiveness of programmes to reduce obesity may vary by SES group, and that sub-group analyses by SES may be warranted.

We also find some evidence that the association between obesity and life expectancy varies by age, and that it is reduced or eliminated in older women. Similar findings have been reported in other studies (for example, Al Snih et al., 2007; Bender et al., 1998; Stevens et al., 1998; Diehr et al., 1998; Grabowski & Ellis, 2001). Al Snih et al (2007) suggest a number of possible explanations: (1) that factors other than obesity obscure the association between obesity and mortality; (2) that BMI is a poor marker for adiposity in older persons; (3) that the relationship is attenuated by selective survival; and, (4) that obesity might have a protective effect at older ages that is less important at younger ages. Given the covariates in our models, and allowing for interactions between them, as well as the use of frailty models to adjust for unobservable heterogeneity we suggest that (1) and (3) are unlikely to explain our findings but further research would be beneficial.

Our study has a number of limitations that should be borne in mind. First, as with other studies, our obesity data are measured once for each individual at baseline; it would be preferable to have repeated measures over time as we do not capture obesity onset timing which might have an impact on survival. Second, the relatively small sample size at higher BMI levels does not allow us to divide our sample into additional obesity categories. For example, in the obese group, BMI ≥ 40 kg/m^2 may have a different impact on life expectancy to 30 kg/m$^2 \leq$ BMI <35 kg/m^2. Third, our measure of obesity is BMI, which has been criticised, e.g., because it does not incorporate body fat, with body fat content being what is actually the independent predictor of ill health (Burkhauser & Cawley, 2008). Related to this, as noted, BMI might also be less appropriate when analysing the impact on survival among persons of different ages.

To summarise, we find that obesity is negatively associated with survival, and that SES is positively associated with survival, in both men and women. There is no evidence of interactions between obesity and SES in predicting survival in men, but these interactions are present in women. Obesity is associated with lower survival in women except for older women in higher SES groups, who have a longer predicted survival than women of normal weight in this group.

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Appendix A

Table A.1. Summary statistics of covariates used

	Men				Women			
	All	Normal weight	Overweight	Obese	All	Normal weight	Overweight	Obese
Age (mean)	58	58	58	58	58	57	60	58
SES groups								
1 (most deprived)	23	24	21	26	26	23	29	32
2	24	24	23	23	26	25	27	30
3	24	21	27	31	26	27	25	24
4 (least deprived)	29	31	29	19	22	26	18	15
Missing income								
Yes	12	10	14	14	22	22	22	18
No	88	90	86	86	78	78	78	82
Ethnicity								
White European	97	97	97	98	98	98	97	97
Other	2	2	2	2	2	1	2	3
Not answered	1	1	1	0	1	1	1	1
Regular smoker								
Yes	32	39	25	21	28	31	23	23
No	68	61	75	79	72	69	77	77
Ex-smoker								
Yes	44	37	48	58	22	22	25	22
No	56	63	52	42	78	78	75	78
Marital status								
Married	82	80	84	77	70	72	69	67
Single	6	7	5	9	5	6	4	4
Separated	2	2	1	2	2	2	2	1
Divorced	3	4	2	4	4	5	3	5
Widowed	7	8	7	8	19	16	22	23
Area								
London	11	12	10	7	9	19	17	14
Wales	5	5	6	8	5	5	5	8
North	6	5	6	5	7	7	7	7
North West	12	11	13	13	13	13	14	12
Yorks/Humber	8	7	9	7	10	10	9	11
West Midlands	8	9	7	5	8	8	9	9
East Midlands	8	9	7	5	8	8	7	7
East Anglia	4	3	5	5	4	4	4	4
South West	10	10	9	12	8	8	9	8
South East	19	21	19	14	18	19	17	14
Scotland	11	8	10	15	10	9	10	12
Educational qualifications								
Degree or equivalent	13	16	12	7	11	13	9	7
Higher education below degree	9	8	9	7	8	9	7	8
NVQ3/GCE A Level or equivalent	3	4	3	2	4	5	3	3
NVQ2/GCE O Level or equivalent	9	9	9	9	9	10	8	8
Other	7	7	7	8	3	4	3	2
No qualification	59	56	60	68	65	60	71	72
Social class of household reference person								
Professional	5	7	5	2	6	7	5	2
Managerial technical	24	22	27	22	26	28	23	19
Skilled non-manual	11	11	10	10	12	13	12	10
Skilled manual	38	37	39	41	34	30	35	43
Semi-skilled manual	17	17	15	18	17	16	18	18
Unskilled manual	6	6	5	7	5	5	5	7
Other	0	0	0	0	1	1	2	1
Economic activity status for last week								
Working full time	54	54	56	54	19	21	19	14
Working part time	3	3	2	3	21	23	19	18
Unemployed	6	6	5	8	1	1	2	1
Permanently sick or disabled	5	5	5	5	2	2	1	3
Retired	32	32	31	31	39	34	45	41
Keeping house	0	0	0	0	18	18	14	23
Full time student	0	0	0	0	0	0	0	0
Bedrooms in household								
One	7	8	5	5	8	8	9	9
Two	26	25	27	26	27	25	30	25
Three	54	52	55	57	49	50	45	55
Four or more	14	15	13	12	16	16	16	11
Housing tenure								
Own accommodation	65	64	67	59	64	69	60	56
Rent	35	36	31	41	36	31	40	44

Notes:

All values are % unless otherwise indicated.

Appendix B

Table B.1. Results of Cox proportional hazards models controlling for individual and household characteristics

	Main effects				BMI interacted with SES				BMI interacted with age				Fully interacted			
	Men		Women		Men		Women		Men		Women		Men		Women	
	Hazard ratio	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**	**Hazard ratio**	**z**
BMI																
Normal weight	Base category		Base category		Base category		Base category		Base category		Base category		Base category		Base category	
Overweight	1.043	0.61	0.974	-0.36	0.988	-0.1	1.054	0.5	0.647	-1.03	1.316	0.59	0.693	-0.71	2.677	1.58
Obese	1.337	2.63	1.365	3.42	1.225	1.03	1.452	2.9	1.350	0.43	4.514	2.73	1.511	0.48	18.961	3.96
SES quartile																
1 (most deprived)	Base category		Base category		Base category		Base category		Base category		Base category		Base category		Base category	
2	0.823	-2.42	0.901	-1.25	0.684	-3.17	1.015	0.13	0.796	-2.76	0.938	-0.75	0.680	-3.19	1.113	0.87
3	0.688	-3.89	0.73	-2.96	0.688	-2.67	0.757	-1.92	0.687	-3.88	0.749	-2.65	0.675	-2.71	0.882	-0.81
4 (least deprived)	0.55	-5.22	0.543	-4.33	0.615	-3.15	0.650	-2.44	0.552	-5.13	0.563	-3.96	0.599	-3.15	0.783	-1.32
BMI*SES																
Overweight*SES quartile 2					1.306	1.58	0.785	-1.38					1.328	1.66	0.700	-1.88
Overweight*SES quartile 3					1.018	0.1	1.101	0.47					1.067	0.33	0.919	-0.36
Overweight*SES quartile 4					0.812	-0.99	0.679	-1.31					0.866	-0.63	0.544	-1.86
Obese*SES quartile 2					1.440	1.34	1.041	0.19					1.424	1.28	0.750	-1.25
Obese*SES quartile 3					0.987	-0.05	0.768	-0.96					0.976	-0.08	0.456	-2.52
Obese*SES quartile 4					0.867	-0.35	0.697	-0.9					0.830	-0.42	0.367	-2.28
Age																
Age	1.169	5.11	1.162	4.91	1.170	5.05	1.164	4.93	1.169	5.02	1.155	4.55	1.170	5.01	1.166	4.82
Age squared	1.000	-2.08	1.000	-1.85	1.000	-2.03	1.000	-1.85	0.999	-2.13	1.000	-1.38	0.999	-2.08	1.000	-1.51
BMI*age																
Overweight*age									1.007	1.15	0.995	-0.67	1.005	0.71	0.987	-1.53
Obese*age									1.000	-0.02	0.982	-2.17	0.997	-0.26	0.965	-3.47
Observations	1832		2230		1832		2230		1832		2230		1832		2230	
Test for proportional hazardsψ	*P*=0.94		*P*=0.36		*P*=0.73		*P*=0.57		*P*=0.97		*P*=0.50		*P*=0.82		*P*=0.66	

Notes:
Controlling for smoking, ethnicity, marital status, area and missing income.
ψ $P<0.05$ means that the proportional hazard assumption is violated.

B

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