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Impact of obesity on life expectancy among different European countries, 1975-2012

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Abstract

Objective: This study assesses the impact of obesity on life expectancy for 26 European national populations and the USA over the 1975-2012 period.

Design: Secondary analysis of population-level obesity and mortality data.

Setting: European countries, namely Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom (UK); and the USA.

Participants: National populations aged 18–100 years, by sex.

Measurements: Using data by age and sex, we calculated obesity-attributable mortality by multiplying all-cause mortality (Human Mortality Database) with obesity-attributable mortality fractions (OAMFs). OAMFs were obtained by applying the partially adjusted method to obesity prevalence data (NCD Risk Factor Collaboration) and European Relative Risks (RRs) (DYNAMO). We estimated potential gains in life expectancy at birth (PGLE) by eliminating obesity-attributable mortality from all-cause mortality using associated single-decrement life tables.

Results: In the 26 European countries in 2012, PGLE due to obesity ranged from 0.86 to 1.67 years among men, and from 0.66 to 1.54 years among women. In all countries, PGLE increased over time, with an average annual increase of 2.68% among men and 1.33% among women. Among women in Denmark, Switzerland, and Central and Eastern European countries, the increase in PGLE levelled off after 1995. Without obesity, the average increase

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3 in life expectancy between 1975 and 2012 would have been 0.78 years higher among men
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5 and 0.30 years higher among women.
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9 **Conclusions:** Obesity was proven to have an impact on both life expectancy levels and
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11 trends in Europe. The differences found in this impact between countries and the sexes can
12
13 be linked to contextual factors, as well as to differences in people's ability and capacity to
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15 adopt healthier lifestyles.
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19 **Keywords:** Obesity, life expectancy, Europe, USA
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22 23 **Article Summary**

24 25 **Strengths and limitations of the study**

- 26
27 • This is the first study to assess the impact of obesity on life expectancy at birth over
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29 time, and we do so here for 26 European countries and the USA.
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- 32
33 • We used recent long-term comparable data on obesity prevalence based on
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35 population-based measurement studies, and European relative risks of dying from obesity by
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37 age and sex from a recent meta-analysis.
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- 40
41 • Because of remaining data limitations regarding prevalence and relative risks, we had
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43 to use a fairly simple – albeit common applied - methodology to estimate obesity-
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45 attributable mortality.
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Introduction

Obesity is a global epidemic (1), with Europe currently ranking second worldwide after the USA (2). Over the last 20 years obesity prevalence has increased threefold in Europe, (3) although not uniformly across countries (4). Estimates for 2014 indicate that obesity varied threefold across European countries, ranging from a low of 9% in Romania to a high of 26% in Malta (5). Obesity constitutes a serious health burden at the individual and population levels because it is associated with an increased risk of morbidity (6), and mortality (7). However, the potential impact of the increase in obesity on life expectancy trends remains largely unknown (8).

The few existing studies that assessed the impact of obesity on life expectancy at the population level provided estimates at one specific point in time only (9, 10). Olshansky et al. found that if obesity was eliminated, life expectancy at birth (e_0) in the USA in 2000 would be 0.21 to 1.08 years higher, depending on gender and ethnicity (9). Preston et al. (10) estimated for 16 low-mortality countries in 2006 that the reduction in life expectancy at age 50 (e_{50}) due to obesity was greatest in the USA, at more than 1.5 years; and ranged from 0.50 to 1.19 years for women and from 0.72 to 1.37 years for men in European countries.

Gaining insight into the impact of obesity on trends in life expectancy is especially relevant (11) given the marked differences in life expectancy trends across Europe (12). In Western European countries, e_0 has been increasing steadily, and has risen six to eight years since 1970. But in Central and Eastern Europe (CEE), e_0 stagnated or even declined between the 1970s and the 1980s, and did not start increasing again until the 1990s. There are also marked differences in e_0 trends between individual European countries (12).

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3 In light of these important differences between European countries in both obesity
4 prevalence and life expectancy over time, our aim is to assess the impact of obesity on long-
5 term trends in life expectancy across a wide range of European countries.
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10 **Data and Methods**

11 **Setting**

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14 We studied the impact of obesity on life expectancy by sex over the 1975-2012 period in 26
15 European countries: Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia,
16 Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the
17 Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden,
18 Switzerland, Ukraine, the United Kingdom (UK); and the USA as a comparison country (10).
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30 **Data**

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33 Long-term comparable obesity prevalence data (BMI \geq 30kg/m²) by country, sex, age (18-19,
34 20-24, ..., 85+), and year (1975-2012), based on population-based measurement studies, were
35 obtained from the NCD Risk Factor Collaboration study (13). These validated data comprise
36 the available measured height and weight data, supplemented with estimates based
37 on information from other years and related countries from a Bayesian hierarchical model
38 (13).
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49 The age- (<50, 50-59, 60-69 and \geq 70 years) and sex-specific relative risks (RRs) of
50 dying from obesity (see Appendix Table S1) came from a review of studies mainly conducted
51 in Western Europe and the USA (14). These age- and sex-specific RRs were largely in line
52 with the overall European RR of 1.64 recently estimated by the Global BMI Mortality
53 Collaboration (15).
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All-cause mortality numbers and exposure population data by single year of age, sex, and year were obtained from the Human Mortality Database (16).

Patient and Public Involvement

No patients were involved in this study.

Methods

We performed our analyses separately by country and sex, based on data by single year of age (18-100). The obesity prevalence data were turned into single-age prevalence (18-100) by applying Loess smoothing (17). The RRs were turned into single-year RRs (18- 100) using linear regression.

To estimate the obesity-attributable mortality fraction (OAMF) – i.e., the share of all-cause mortality due to obesity – we used the Rockhill formula to estimate OAMFs by age (a) and sex (s) (18).

$$OAMF_{a,s} = \frac{P_{a,s} \cdot (RR_{a,s} - 1)}{1 + (P_{a,s} \cdot (RR_{a,s} - 1))} \text{ (Equation 1)}$$

where P is the obesity prevalence. We then weighted the $OAMF_{a,s}$ with the corresponding number of deaths.

For the estimation of the impact of obesity on life expectancy (see 2.3.2) we needed age-and sex-specific (non-) obesity-attributable mortality rates. These were obtained by multiplying $OAMF_{a,s}$ and $[1 - OAMF_{a,s}]$, respectively, with age- and sex-specific all-cause mortality rates.

To ensure comparability across countries, over time, and between men and women, we applied direct age- and sex-standardisation (19) to obesity prevalence, obesity-

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3 attributable mortality fractions, and obesity-attributable mortality rates, using the European
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5 population of 2011 (20) as the standard.
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9 To assess the impact of adult obesity on e_0 , we calculated for each country the
10
11 potential gain in life expectancy (PGLE) if obesity-attributable mortality were eliminated, by
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13 calendar year and sex. First, we calculated e_0 by applying standard life table techniques to
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15 age-specific all-cause mortality rates (0-100) (19). Second, we applied associated single-
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17 decrement life tables (ASDLT) (19) to age- and sex-specific non-obesity-attributable mortality
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19 rates (0-100) to obtain e_0 if obesity-attributable mortality were eliminated. The PGLE
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21 represents the difference between the e_0 based on the ASDLT and the original e_0 .
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26 To summarise the changes in PGLE across countries, we estimated the average
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28 annual changes in PGLE (in %):
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$$31$$

$$32 \quad \text{Average annual changes in PGLE (\%)} = \frac{\sum_{t=1976}^{2012} \frac{(PGLE_t - PGLE_{t-1})}{PGLE_{t-1}}}{2012 - 1975} \times 100$$

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39 To assess the impact of obesity on time trends in e_0 between 1975 and 2012, we
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41 subtracted the observed change in e_0 from the change in e_0 without obesity. The change in
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43 e_0 without obesity was obtained by using the e_0 values from the associated single-decrement
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45 life tables applied to non-obesity-attributable mortality for 1975 and 2012.
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49 Results

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52 For the 26 European countries, the age-standardised obesity-attributable mortality fraction
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54 (OAMF) was, on average, 11% among men and 10% among women in 2012. For the USA,
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56 these estimates were substantially higher; i.e., 15% and 14%, respectively. The average
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OAMF levels were higher in Northern, Western, and Southern Europe combined (hereafter, Western Europe) than in CEE among men, while the opposite was the case among women.

OAMFs were increasing over time for all countries and both sexes, although not to the same extent (see Figure 1, Figure S1). In Western Europe, OAMFs generally increased over the 1975-2012 period, and at a faster pace among men. In CEE, by contrast, OAMFs clearly stagnated, and even declined between 1990 and 2000. The overall increase in OAMFs was greatest in the USA, Ireland, Norway (men), and the UK (women).

Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European countries (by 5 regions) and USA, 1975-2014, 18-100 years

<approximately here>

In the 26 European countries in 2012, estimates of potential gains in life expectancy at birth (PGLE) if obesity was eliminated ranged from 0.86 to 1.67 years among men (1.22 on average) and from 0.66 to 1.54 years (0.98 on average) among women (Figure 2; Figure S2 and Table S2 Appendix). Among men in the USA, the PGLE estimate was, at 1.73 years, slightly higher than the highest estimate in Europe; and among women in the USA, the PGLE estimate was, at 1.44 years, the second-highest after the estimate for Russia. The average PGLE estimate was 1.08 among men and 0.86 among women in Western Europe, and was 1.44 among men and 1.16 among women in CEE (see Appendix Table S2).

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3 **Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality**
4 **was eliminated, in 26 European countries (differentiating Western and Central Eastern**
5 **Europe) and the USA, 1975-2012**
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14 Overall, from 1975 to 2012, PGLE due to obesity increased in all of the countries (Figure
15 2, Figure S2, Figure 3, 4). The increase was greater among men (average annual increase of
16 2.68%) than among women (average annual increase of 1.33%), was largest among men in
17 Portugal and Belarus and among women in Portugal, and was substantial among men and
18 women in Norway (Figure 3, 4). While there was a general increase in PGLE due to obesity,
19 this trend stagnated among women in CEE from around 1990 onwards, and levelled off after
20 1995 among women in Denmark and Switzerland.
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32 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
33 **26 European countries and the USA between 1975-2012, in men**
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41 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
42 **26 European countries and the USA between 1975-2012, in women**
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48 Table 1 shows the impact of obesity on time trends in life expectancy at birth (e_0).
49 Overall, the average increase in e_0 between 1975 and 2012 was 7.26 years for men and 6.28
50 years for women in the 26 European countries. Without obesity, the average increase in e_0
51 would have been 8.04 years for men and 6.58 years for women; or 0.78 and 0.30 years
52 higher, respectively. Among men, obesity had the greatest impact on e_0 trends in Lithuania
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and the USA (more than one year), and the smallest impact in Iceland and Sweden (0.5 years). Among women, obesity had the greatest impact on e_0 trends in the USA and Ireland (0.7 years) and the smallest impact in Estonia and the Czech Republic (less than 0.1 year).

Table 1: Impact of obesity on trends in life expectancy at birth (e_0) in 26 European countries and USA 1975-2012, by sex

Country	Change in e_0 with obesity 2012-1975 (years)		Change in e_0 without obesity 2012-1975 (years)		Effect of obesity on e_0 change 2012-1975 (years)	
	Men	Women	Men	Women	Men	Women
	Austria	10.62	8.61	11.25	8.95	0.63
Belarus	-0.55	1.43	0.46	1.83	1.00	0.40
Belgium	8.85	7.63	9.46	7.99	0.61	0.36
Czech Republic	7.97	6.98	8.66	7.03	0.69	0.05
Denmark	6.78	5.03	7.40	5.36	0.63	0.33
Estonia	6.43	6.42	7.26	6.46	0.82	0.04
France	9.49	7.99	10.17	8.30	0.68	0.31
Finland	10.07	7.26	10.82	7.75	0.74	0.50
Hungary	5.29	6.18	6.17	6.36	0.87	0.18
Iceland	9.02	5.19	9.51	5.51	0.48	0.32
Ireland	9.40	8.40	10.22	9.10	0.83	0.69
Italy	10.19	8.56	10.81	8.89	0.62	0.33
Latvia	4.91	4.53	5.82	4.70	0.90	0.18
Lithuania	2.01	3.80	3.14	4.06	1.13	0.26
Luxembourg	11.78	9.27	12.50	9.65	0.72	0.37
Netherlands	7.68	5.10	8.26	5.6	0.56	0.49
Norway	7.70	5.33	8.42	5.86	0.74	0.51
Poland	5.90	6.74	6.81	7.00	0.91	0.27
Portugal	12.14	10.87	12.91	11.26	0.77	0.40
Russian Federation	2.05	2.62	3.06	2.89	1.02	0.28
Slovakia	5.65	5.82	6.52	6.16	0.88	0.34
Spain	8.82	8.75	9.62	9.14	0.79	0.39
Sweden	7.69	5.59	8.18	5.93	0.49	0.33
Switzerland	8.98	6.63	9.55	6.93	0.58	0.30
Ukraine	0.48	1.73	1.26	1.94	0.78	0.21
United Kingdom	9.46	6.96	10.20	7.55	0.74	0.59
USA	7.86	4.89	8.90	5.61	1.04	0.71
Average CEE countries	4.01	4.63	4.92	4.84	0.90	0.22

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3 **Average Western** 9.10 7.09 9.76 7.50 0.66 0.41
4 **countries**
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12 **Discussion**

15 **Summary of results**

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18 In the 26 European countries studied, the share of mortality due to obesity in 2012 was, on
19 average, 11% among men and 10% among women. PGLE due to obesity in 2012 ranged from
20 0.86 to 1.73 years among men, and from 0.66 to 1.54 years among women. Overall, PGLE
21 increased between 1975 and 2012, albeit more quickly among men (average annual
22 increase: 2.68%) than among women (1.33%). Among women in Denmark, Switzerland, and
23 the CEE countries the increase in PGLE levelled off after 1995. Without obesity, the average
24 increase in e0 between 1975 and 2012 would have been 0.78 years higher among men and
25 0.30 years higher among women.
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39 **Evaluation of data and methods**

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42 Using the recent advances in obesity data, it is now possible to study the impact of obesity
43 on life expectancy for a large number of countries and a long period of time. Two
44 methodological issues warrant our attention, however.
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49 First, in calculating the share of mortality due to obesity (OAMF), which also forms
50 the basis for our PGLE calculations, we were hindered by limitations in the available
51 prevalence and RRs data, which also affected the method used. As has previously been
52 documented, OAMF estimates are sensitive to the data and the methods used (21).
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59 In selecting obesity prevalence data, we used the longest validated time series based
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3 on population-based measurement studies that are suitable for studying the impact of obesity
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5 on long-term life expectancy trends across Europe (13). For those countries with less available
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7 obesity data – especially CEE countries – a portion of the data we used were modelled, and
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9 these should be treated with some caution (13).
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13 Because age- and sex-specific RRs of mortality associated with obesity are not
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15 available by country and year, we applied to all of the countries studied time-constant age-
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17 and sex-specific RRs from Western European and US populations that are largely suitable for
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19 our setting. However, literature for the USA has demonstrated that RRs have been changing
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21 over time, pointing to both a decline (22-24) and an increase (25). Before implementing
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23 time-variant European RRs, more information on their direction is required. Similarly,
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25 comparable country-specific RRs are urgently needed.
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30 Based on the available data, only a fairly simple – albeit common applied –the
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32 partially adjusted method could be applied (21) to estimate the OAMFs. The application of a
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34 more advanced methodology (21) could have affected the OAMFs and thus the PGLE levels,
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36 but less the trends (26).
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40 Second, besides being the result of the OAMFs, the PGLE estimates can also be
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42 affected by all-cause mortality levels and trends as age- and sex-specific all-cause mortality
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44 rates are used to estimate PGLE. Since all-cause mortality fluctuated greatly in CEE in the
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46 analysed period (12), short-term variations in PGLE in CEE countries should be treated with
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48 more caution.
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51 **Explanation of results**

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55 In 2012, the PGLE due to obesity were, on average, 1.22 years for men and 0.98 years for
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57 women in the 26 European countries, and 1.73 years for men and 1.43 years for women in
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59 the USA. A comparison of our 2006 e50 estimates with those of Preston et al. (10) for the
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3 same countries uncovered only small differences, except among men in the USA (our
4 estimate was 0.56 years lower) and women in the UK (our estimate was 0.29 years lower)
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6 (see Appendix Table S3). Given that approximately the same methodology was used to
7
8 estimate the OAMFs, the observed differences are most likely due to the use of different
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10 obesity prevalence and RRs data. Preston used prevalence data from national representative
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12 surveys and RRs from the Prospective Studies collaboration (14).
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18 To further evaluate our observed PGLE levels, we compared them with own PGLE
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20 estimates for smoking and alcohol (27). Our PGLE estimates for smoking were 2.38 years for
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22 men and 1.00 year for women in Western Europe, and 3.82 years for men and 0.67 years for
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24 women in CEE. Our PGLE estimates for alcohol were 0.90 years for men and 0.44 years for
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26 women in Western Europe, and 2.15 years for men and 1.00 year for women in CEE (27).
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28 Thus, obesity's impact on life expectancy lies between that of smoking and alcohol, and can
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30 be considered significant.
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37 In our study, we found that PGLE due to obesity was increasing, but that this trend
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39 differed across countries and between the sexes. This overall trend can be explained by the
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41 general increase in obesity prevalence in European countries (see Appendix Figure S3) (13)
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43 and the resulting growth in the burden of obesity (3), which is also reflected in the OAMFs
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45 (Figure 1, Figure S1) in these countries.
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50 At the same time, parts of the observed variation in the increase in PGLE estimates
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52 across the USA, Western Europe, and CEE and between the sexes reflect differences in the
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54 onset, the development, and the impact of the obesity epidemic in these countries and in
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56 men and women. Across the countries studied, the absolute increase in PGLE was largest
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58 among women and second-largest among men in the USA. This pattern is in line with
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3 evidence showing that between 1980 and 2008, obesity increased much more in the USA
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5 than in Europe (1, 28). This rapid progression of the obesity epidemic in the USA and its large
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7 impact on life expectancy has been attributed to an increasingly obesogenic environment
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9 caused by factors such as changes in food preparation and processes that promote the
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11 consumption of calorically dense foods, and a pronounced decrease in physical activity levels
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13 (29). The obesity epidemic has progressed more slowly in Western Europe than in the USA
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15 (1, 13). However, obesity levels in countries like the UK and Ireland are rapidly approaching
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17 those in the USA (30), as our PGLLE estimates also show.
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24 In the CEE countries, the PGLLE trends track the evolution of the obesity epidemic in
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26 that region (see Appendix Figure S3). Obesity levels have been higher in CEE than in Western
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28 Europe since 1980 (31, 32), which suggests that the epidemic started earlier in CEE. As a
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30 result of this earlier onset, the impact of obesity (as expressed in terms of OAMF and PGLLE)
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32 in the 1970s and 1980s was at times even greater in CEE than in the USA, especially among
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34 women. While there are many potential explanations for this early onset of the obesity
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36 epidemic in CEE, the available data indicate that the main factors were the relatively high
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38 total energy supply and energy intake in CEE in those years (33).
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45 The overall progress of the obesity epidemic was lower in CEE than in Western
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47 Europe, and the increase was not constant (1). Indeed, in CEE, increases in obesity
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49 prevalence (1, 34), OAMFs, and PGLLE stagnated in the 1980-2008 period, more pronounced
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51 in the 1990s (1, 34). This pattern could be explained by the decrease in energy supplies at
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53 the beginning of the 1990s in CEE (31) resulting from the dramatic economic and political
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55 changes in those countries (1, 31, 34). Among CEE women, the increase in obesity starting in
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57 the 1990s was smaller than it was in the previous period, and was smaller than it was among
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3 CEE men. The lower risk of obesity observed among women than among men with low
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5 socioeconomic status (SES) in low-income countries (35) may explain this difference.
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9 In Western Europe, a stagnation in PGLE levels was observed among women in
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11 Denmark and Switzerland after 1995. This finding seems to be in line with studies reporting a
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13 levelling-off of mean BMI since the 1990s (36); and in specific sub-populations, such as
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15 adults with high SES in regions within Switzerland, Italy, France, and Finland (31). Although
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17 dietary and physical activity information is spreading equally across socioeconomic groups,
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19 those with higher SES have a greater ability and capacity to adopt a healthier dietary and
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21 physical activity pattern (37). In addition, it appears that higher SES women in particular are
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23 more health-conscious, have healthier food habits, and are more prone to follow nutritional
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25 recommendations (38) as they are under greater social pressure to be thin (39). Similarly,
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27 countries with higher income levels and lower levels of inequality (40), like Switzerland and
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29 Denmark, tend to have lower obesity levels, especially among women.
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37 When we considered the impact of obesity on life expectancy in the 26 European
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39 countries, we found that without obesity, the increase in e_0 between 1975 and 2012 would
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41 have been, on average, 0.78 years higher among men and 0.30 years higher among women.
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43 These figures account for approximately 10% of the average change in e_0 between 1975 and
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45 2012 among men, and 5% among women. It is therefore clear that the impact of obesity on
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47 changes in e_0 should not be ignored. Moreover, the impact of obesity on life expectancy
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49 trends is likely to increase, given that this impact is already substantially greater in the USA
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51 (13% among men and 15% among women), and that obesity prevalence is still increasing
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53 rapidly in most European countries (see Appendix Figure S3).
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60 **Conclusion and implications**

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3 Obesity was proven to have an impact on both life expectancy levels and trends in
4 Europe. The observed differences in the increase in the impact of obesity across countries
5 and between the sexes reflect differences in the onset and the progression of the obesity
6 epidemic, and can be linked to contextual factors (economic conditions, obesogenic
7 environment, energy supplies), as well as to differences in people's ability and capacity to
8 adopt healthier lifestyles.
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18 It is likely that in the future obesity will have a larger impact on mortality and life
19 expectancy in Europe, as obesity continues to increase in the majority of countries. It is
20 therefore crucial that effective public health initiatives are undertaken to tackle the obesity
21 epidemic and its effects on public health. Such initiatives should address the multifactorial
22 and complex obesity aetiology; the clear differences between countries and the sexes; as
23 well as the factors underlying these differences, such as contextual factors and differences in
24 individuals' ability and capacity to adopt healthier lifestyles.
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Conflict of Interest

None declared.

Author contribution

N.Vidra contributed to the conception and design of the work; to the acquisition, analysis, and interpretation of data for the work; drafted and revised the work critically for important intellectual content; approved the final version of the work to be published and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

S. Trias-Llimós contributed to the analysis, and interpretation of data for the work; revised it critically for important intellectual content; approved the final version of the work to be

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3 published and agrees to be accountable for all aspects of the work in ensuring that questions
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5 related to the accuracy or integrity of any part of the work are appropriately investigated
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7 and resolved.
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11 F. Janssen contributed to the conception and design of the work; to the interpretation of
12
13 data for the work; revised the work critically for important intellectual content; approved
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15 the final version of the work to be published and agrees to be accountable for all aspects of
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17 the work in ensuring that questions related to the accuracy or integrity of any part of the
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19 work are appropriately investigated and resolved.
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23 24 25 **Data statement**

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28 Obesity prevalence data can be obtained from NCD Risk Factor Collaboration (NCD-RisC)
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30 (www.ncdrisc.org).
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34 All-cause mortality and exposure population data can be obtained from the Human
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36 Mortality Database (<http://www.mortality.org>).
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40 41 **Acknowledgements**

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45
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47
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49
50 (www.ncdrisc.org) for sharing the obesity data.
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54 This work is financed by the Netherlands Organisation for Scientific Research (NWO) as part
55
56 of the research programme "Smoking, alcohol, and obesity, ingredients for improved and
57
58 robust mortality projections, grant no. 452-13-001. See www.futuremortality.com
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Figure legends

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55 **Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European countries (by 5**
56 **regions) and USA, 1975-2014, 18-100 years**
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Footnote:

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59 Countries within the same region are presented with the same colour
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3 **Central Europe:** Czech Republic, Hungary, Poland, Slovakia

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5 **Eastern Europe:** Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

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7 **Northern Europe:** Denmark, Finland, Iceland, Norway, Sweden

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9 **Southern Europe:** Italy, Portugal, Spain

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11 **Western Europe:** Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom

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13 **USA:** United States of America

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16 **Figure 2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was**
17 **eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the**
18 **USA, 1975-2012, 18-100 years**

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25 Countries within the same region are presented with the same colour

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27 **Central Eastern Europe:** Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Ukraine

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29 **Western Europe:** Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain,
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31 Sweden, Switzerland, United Kingdom

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33 **USA:** United States of America

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35 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
36 **26 European countries and the USA between 1975-2012, in men**

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40 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
41 **26 European countries and the USA between 1975-2012, in women**

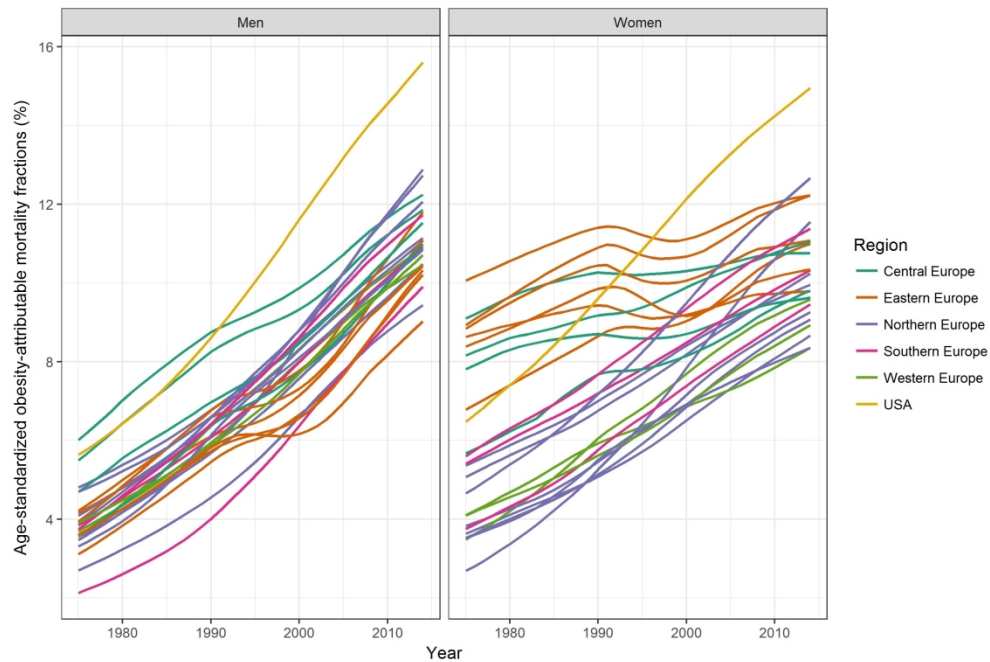


Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European countries (by 5 regions) and USA, 1975-2014, 18-100 years. Footnote: Countries within the same region are presented with the same colour

Central Europe: Czech Republic, Hungary, Poland, Slovakia
 Eastern Europe: Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation
 Northern Europe: Denmark, Finland, Iceland, Norway, Sweden
 Southern Europe: Italy, Portugal, Spain
 Western Europe: Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom
 USA: United States of America

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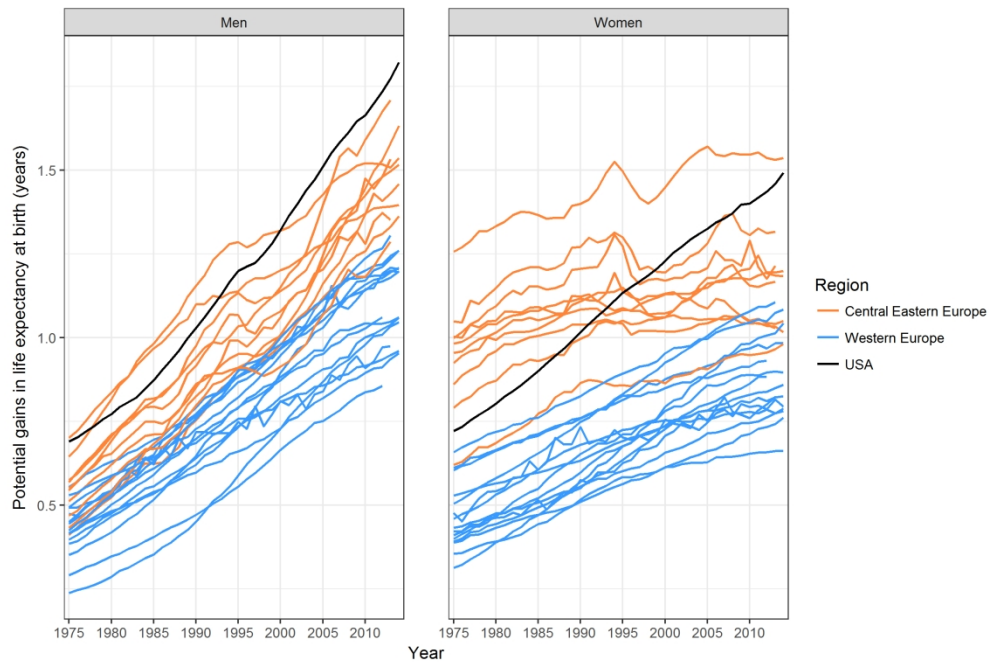


Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, 1975-2012, 18-100 years

Footnote: Countries within the same region are presented with the same colour
 Central Eastern Europe: Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Ukraine
 Western Europe: Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom
 USA: United States of America

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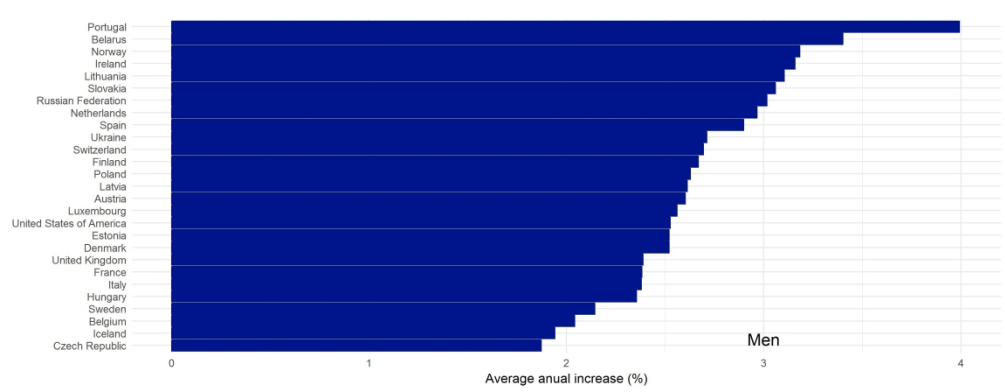


Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in men

1244x472mm (72 x 72 DPI)

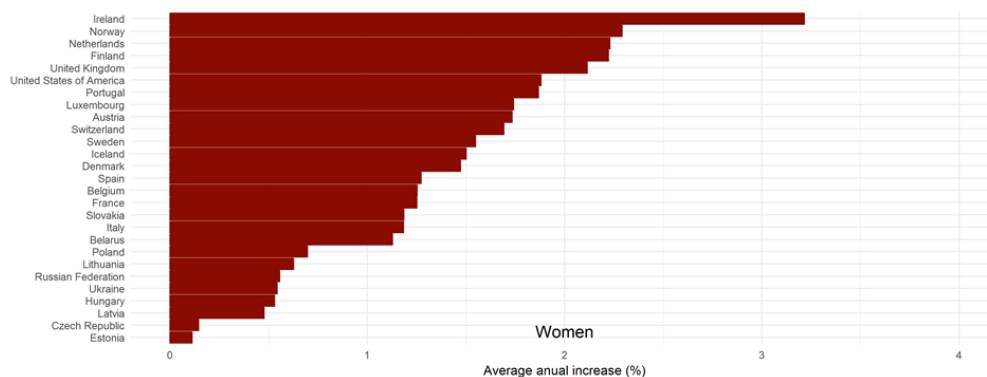


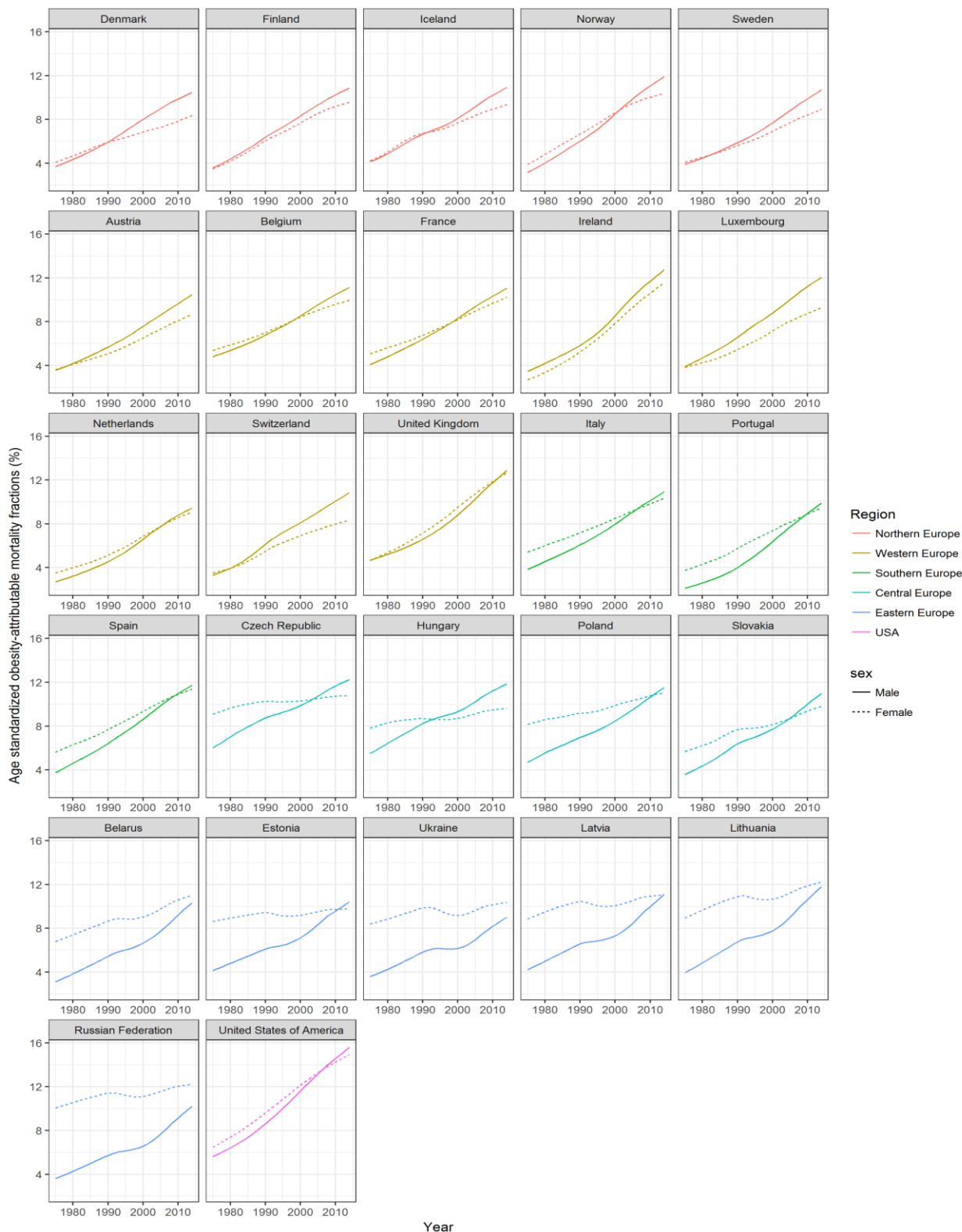
Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in women

Supplementary material**Table S1: Age-and sex-specific RRs of dying from obesity from the Dynamo project (Lobstein et al. 2010)**

Age	RR	
	Men	Women
<50	1.55	1.5
50-59	1.539	1.49
60-69	1.5225	1.475
70+	1.495	1.45

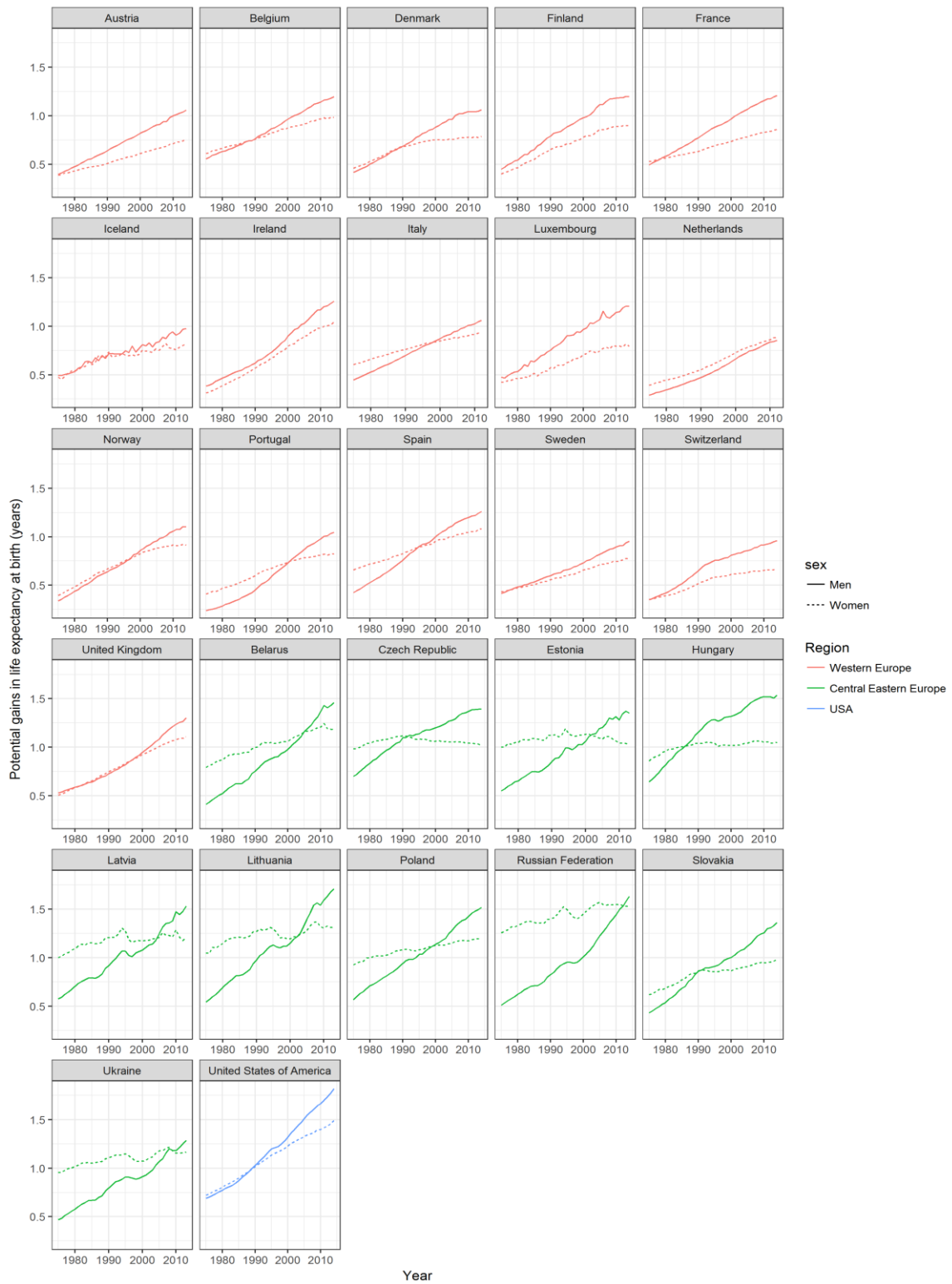
Reference group for the RRs: normal weight (18-24.9 kg/m²)

Figure S1: Age-standardised obesity-attributable mortality fractions in 26 European countries, grouped by 5 regions and USA, 1975-2014, 18-100 years



Countries within the same region are presented with the same colour

Figure S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries, grouped by 2 regions and USA, 1975-2012, 18-100 years



Countries within the same region are presented with the same colour

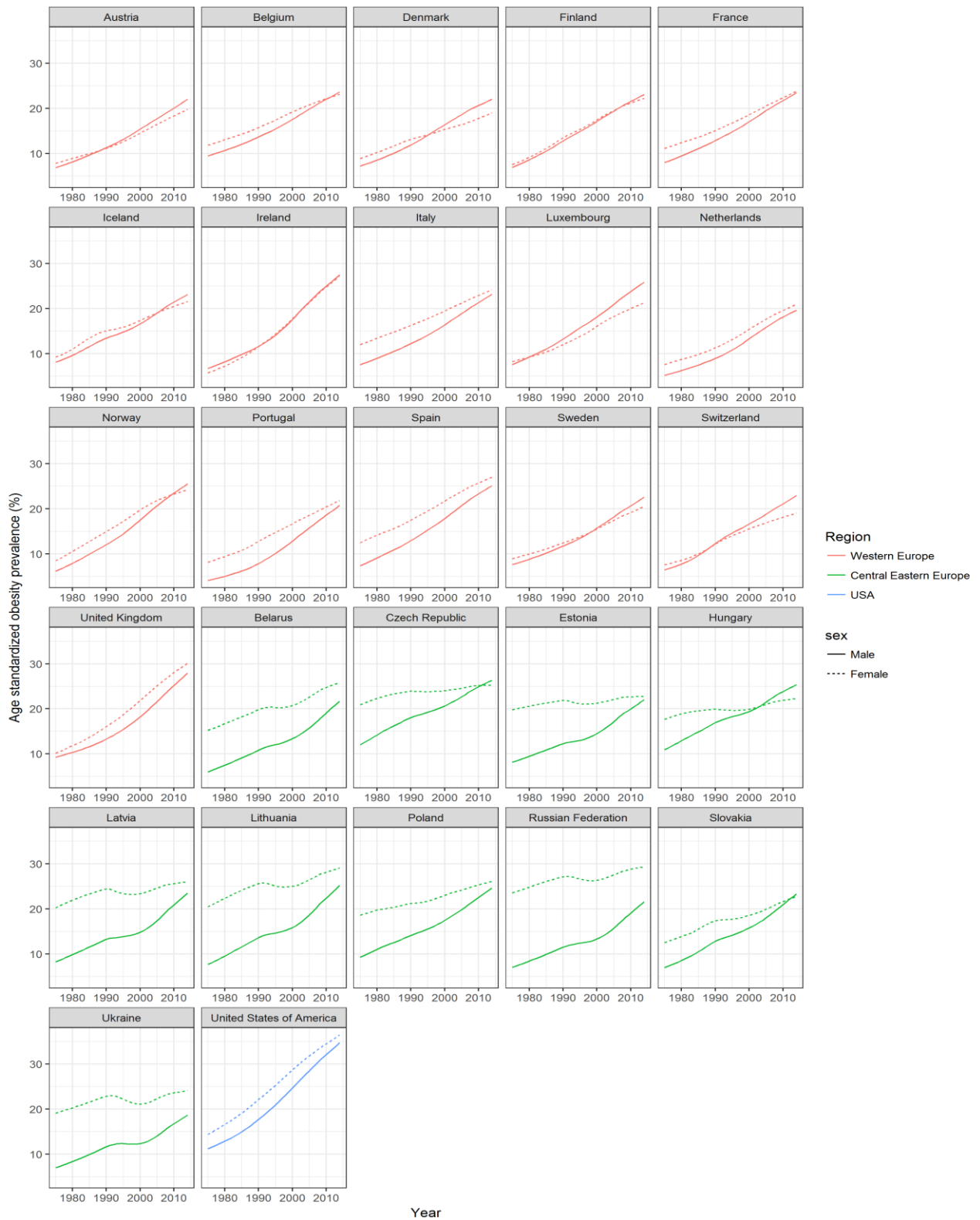
Table S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, in 1975 and 2012, 18-100 years

Country	PGL 1975		PGL 2012	
	Men	Women	Men	Women
Central Eastern Europe (CEE)				
Belarus	0.41	0.79	1.41	1.19
Czech Republic	0.70	0.98	1.39	1.03
Estonia	0.55	1.00	1.37	1.04
Hungary	0.64	0.86	1.52	1.04
Latvia	0.58	1.00	1.48	1.18
Lithuania	0.54	1.05	1.67	1.31
Poland	0.57	0.93	1.48	1.19
Russian Federation	0.51	1.26	1.53	1.54
Slovakia	0.43	0.62	1.31	0.96
Ukraine	0.47	0.95	1.25	1.16
Average CEE	0.54	0.94	1.44	1.16
Western Europe				
Austria	0.40	0.39	1.03	0.73
Belgium	0.55	0.61	1.17	0.97
Denmark	0.42	0.46	1.04	0.79
France	0.49	0.53	1.18	0.84
Finland	0.45	0.40	1.19	0.90
Ireland	0.38	0.31	1.21	1.01
Iceland	0.49	0.48	0.97	0.80
Italy	0.44	0.60	1.06	0.93
Luxembourg	0.47	0.42	1.19	0.79
Netherlands	0.29	0.39	0.86	0.88
Norway	0.34	0.39	1.07	0.91
Portugal	0.24	0.41	1.01	0.81
Spain	0.42	0.66	1.22	1.05
Sweden	0.42	0.43	0.91	0.76
Switzerland	0.35	0.35	0.93	0.66
United Kingdom	0.53	0.50	1.27	1.09
Average Western Europe	0.41	0.48	1.08	0.86
USA	0.69	0.72	1.73	1.44
Average European countries	0.46	0.64	1.22	0.98
Average all countries	0.47	0.64	1.23	1.00

Table S3: Potential gains in life expectancy at age 50 (PGL e50 2006) if obesity-attributable mortality was eliminated, own and Preston estimates, in the same countries studied, in 2006

	PGLE e50 2006, own estimates	PGLE e50 2006, Preston's estimates	Difference
Country			
Men			
Austria	0.81	1.00	-0.19
Belgium	0.95	0.98	-0.03
Czech Republic	1.14	1.34	-0.20
Denmark	0.88	0.82	0.06
France	0.94	0.99	-0.05
Italy	0.88	0.90	-0.02
Netherlands	0.69	0.73	-0.04
Poland	1.14	1.37	-0.23
Spain	1.02	1.15	-0.13
Sweden	0.75	0.72	0.03
Switzerland	0.77	0.79	-0.02
United Kingdom	0.99	1.34	-0.35
USA	1.29	1.85	-0.56
Women			
Austria	0.62	0.71	-0.09
Belgium	0.86	0.73	0.13
Czech Republic	0.87	1.01	-0.14
Denmark	0.71	0.62	0.09
France	0.72	0.52	0.2
Italy	0.84	0.57	0.27
Netherlands	0.76	0.69	0.07
Poland	1.08	1.19	-0.11
Spain	0.95	0.87	0.08
Sweden	0.67	0.63	0.04
Switzerland	0.59	0.50	0.09
United Kingdom	0.94	1.23	-0.29
USA	1.18	1.28	-0.10

Figure S3: Age-standardised obesity prevalence in 26 European countries, grouped by 2 regions and USA, 1975-2012, 18-100 years



Countries within the same region are presented with the same colour

BMJ Open

Impact of obesity on life expectancy among different European countries, 1975-2012

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-028086.R1
Article Type:	Research
Date Submitted by the Author:	28-Apr-2019
Complete List of Authors:	Vidra, Nikoletta; Population Research Centre, Faculty of Spatial Sciences, Demography Trias-Llimós, Sergi; University of Groningen, Population Research Centre Janssen, Fanny; University of Groningen, Population Research Centre; Nederlands Interdisciplinair Demografisch Instituut
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health, Nutrition and metabolism
Keywords:	EPIDEMIOLOGY, NUTRITION & DIETETICS, PUBLIC HEALTH

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Manuscripts

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3 **1 Impact of obesity on life expectancy among different European countries, 1975-2012**
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6 **2** Nikoletta Vidra¹, Sergi Trias-Llimós¹, Fanny Janssen^{1,2}
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24 **8** Corresponding author: Nikoletta Vidra, Population Research Centre, Faculty of Spatial
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58 **19** **Word count: 3669 words**
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6 21 **Abstract**
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9 22 **Objective:** This study assesses the impact of obesity on life expectancy for 26 European
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12 23 national populations and the USA over the 1975-2012 period.
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15 24 **Design:** Secondary analysis of population-level obesity and mortality data.
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18 25 **Setting:** European countries, namely Austria, Belarus, Belgium, the Czech Republic,
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21 26 Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania,
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23 27 Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia,
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25 28 Spain, Sweden, Switzerland, Ukraine, the United Kingdom (UK); and the USA.
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28 29 **Participants:** National populations aged 18–100 years, by sex.
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31 30 **Measurements:** Using data by age and sex, we calculated obesity-attributable mortality by
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34 31 multiplying all-cause mortality (Human Mortality Database) with obesity-attributable
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36 32 mortality fractions (OAMFs). OAMFs were obtained by applying the weighted-sum method
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38 33 to obesity prevalence data (NCD Risk Factor Collaboration) and European Relative Risks (RRs)
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40 34 (DYNAMO). We estimated potential gains in life expectancy at birth (PGLE) by eliminating
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42 35 obesity-attributable mortality from all-cause mortality using associated single-decrement life
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44 36 tables.
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48
49 37 **Results:** In the 26 European countries in 2012, PGLE due to obesity ranged from 0.86 to 1.67
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51 38 years among men, and from 0.66 to 1.54 years among women. In all countries, PGLE
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53 39 increased over time, with an average annual increase of 2.68% among men and 1.33% and
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55 40 among women. Among women in Denmark, Switzerland, and Central and Eastern European
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57 41 countries, the increase in PGLE levelled off after 1995. Without obesity, the average increase
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3 42 in life expectancy between 1975 and 2012 would have been 0.78 years higher among men
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5 43 and 0.30 years higher among women.
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9 44 **Conclusions:** Obesity was proven to have an impact on both life expectancy levels and
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11 45 trends in Europe. The differences found in this impact between countries and the sexes can
12
13 46 be linked to contextual factors, as well as to differences in people's ability and capacity to
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15 47 adopt healthier lifestyles.
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19 48 **Keywords: Obesity, life expectancy, Europe, USA**
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23 49 **Article Summary**

24 25 50 **Strengths and limitations of the study**

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27 51 • This is the first study to assess the impact of obesity on life expectancy at birth over
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29 52 time, and we do so here for 26 European countries and the USA.
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34 53 • We used recent long-term comparable data on obesity prevalence based on
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36 54 population-based measurement studies, and European relative risks of dying from obesity by
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38 55 age and sex from a recent meta-analysis.
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42 56 • Because of remaining data limitations regarding prevalence and relative risks, we had
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44 57 to use a fairly simple – albeit common applied - methodology to estimate obesity-
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46 58 attributable mortality.
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63 Introduction

64 Obesity is a global epidemic (1), with Europe currently ranking second worldwide after the
65 USA (2). Over the last 20 years obesity prevalence has increased threefold in Europe(3),
66 although not uniformly across countries (4). Estimates for 2014 indicate that obesity varied
67 threefold across European countries, ranging from a low of 9% in Romania to a high of 26%
68 in Malta (5). Obesity constitutes a serious health burden at the individual and population
69 levels because it is associated with an increased risk of morbidity (6), and mortality (7).
70 However, the potential impact of the increase in obesity on life expectancy trends remains
71 largely unknown (8).

72 The few existing studies that assessed the impact of obesity on life expectancy at the
73 population level provided estimates at one specific point in time only (9, 10). Olshansky et al.
74 found that if obesity was eliminated, life expectancy at birth (e_0) in the USA in 2000 would
75 be 0.21 to 1.08 years higher, depending on gender and ethnicity (9). Preston et al. (10)
76 estimated for 16 low-mortality countries in 2006 that the reduction in life expectancy at age
77 50 (e_{50}) due to obesity was greatest in the USA, at more than 1.5 years; and ranged from
78 0.50 to 1.19 years for women and from 0.72 to 1.37 years for men in European countries.

79 Gaining insight into the impact of obesity on trends in life expectancy is especially
80 relevant (11) given the marked differences in life expectancy trends across Europe (12). In
81 Western European countries, e_0 has been increasing steadily, and has risen six to eight years
82 since 1970. But in Central and Eastern Europe (CEE), e_0 stagnated or even declined between
83 the 1970s and the 1980s, and did not start increasing again until the 1990s. There are also
84 marked differences in e_0 trends between individual European countries (12).

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3 85 In light of these important differences between European countries in both obesity
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6 86 prevalence and life expectancy over time, our aim is to assess the impact of obesity on long-
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8 87 term trends in life expectancy across a wide range of European countries.
9

10
11 88 Our sole focus is on the impact of obesity, given the significant health burden caused by
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13
14 89 obesity, the large body of literature on its impact, and the well-documented association of
15
16 90 obesity with mortality.
17

19 91 **Data and Methods**

22 92 **Setting**

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24
25 93 We studied the impact of obesity on life expectancy by sex over the 1975-2012 period in 26
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27
28 94 European countries: Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia,
29
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31 95 Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the
32
33
34 96 Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden,
35
36 97 Switzerland, Ukraine, the United Kingdom (UK); and the USA as a comparison country (10).
37

38 98 **Data**

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40
41 99 Long-term comparable obesity prevalence data ($BMI \geq 30 \text{ kg/m}^2$) by country, sex, age (18-19,
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43
44 100 20-24, ..., 85+), and year (1975-2012), based on 1698 population-based measurement studies,
45
46 101 were obtained from the NCD Risk Factor Collaboration study (13). These validated data
47
48
49 102 comprise the available measured height and weight data of 19.2 million participants from
50
51
52 103 representative data sources, supplemented with estimates based on information from other
53
54 104 years and related countries from a Bayesian hierarchical model (13). The same model was
55
56 105 applied to all countries and used as an input the measured weight and height data, including
57
58
59 106 covariates that help predict BMI (13).
60

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3 107 The age- (<50, 50-59, 60-69 and ≥ 70 years) and sex-specific relative risks (RRs) of
4
5
6 108 dying from obesity (see Supplementary Material Table S1) came from a review of studies
7
8 109 mainly conducted in Western Europe and the USA, with the normal-weight category used as
9
10 110 the reference group ($18.5 \leq \text{BMI} \leq 25 \text{ kg/m}^2$) (14). These age- and sex-specific RRs were largely
11
12
13 111 in line with the overall European RR of 1.64 recently estimated by the Global BMI Mortality
14
15 112 Collaboration (7). The differences across age groups found in that study were similar with
16
17
18 113 those reported in our findings (i.e., higher RRs at younger than at older ages), though they
19
20 114 were less distinct (7). In addition, the use of RRs with the normal weight category as the
21
22
23 115 reference category is in line with previous studies that estimated obesity-attributable
24
25 116 mortality (15-19), while the estimation of obesity-attributable mortality with such a RR can
26
27
28 117 be considered the theoretically maximally possible attributable mortality (20).

29
30 118 All-cause mortality numbers and exposure population data by single year of age, sex,
31
32
33 119 year, and country were obtained from the Human Mortality Database (21). These data are of
34
35
36 120 high quality and are widely used within the demographic community and beyond (22).

37 38 39 121 **Patient and Public Involvement**

40
41
42 122 No patients were involved in this study.

43 44 45 123 **Methods**

46
47
48 124 We performed our analyses separately by country and sex, based on data by single year of
49
50
51 125 age (18-100). The obesity prevalence data were turned into single-age prevalence (18-100)
52
53
54 126 by applying Loess smoothing (23). The RRs were turned into single-year RRs (18- 100) using
55
56 127 linear regression.

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3 128 To estimate the obesity-attributable mortality fraction (OAMF) – i.e., the share of all-
4
5
6 129 cause mortality due to obesity – we used the Rockhill formula to estimate OAMFs by age (a)
7
8 130 and sex (s) (24).

$$11 \quad 131 \quad OAMF_{a,s} = \frac{P_{a,s} \cdot (RR_{a,s} - 1)}{1 + (P_{a,s} \cdot (RR_{a,s} - 1))} \text{(Equation 1)}$$

12
13
14
15
16 132 where P is the obesity prevalence. We then weighted the $OAMF_{a,s}$ with the corresponding
17
18 133 number of deaths.

19
20
21 134 For the estimation of the impact of obesity on life expectancy (see 2.3.2) we needed
22
23
24 135 age- and sex-specific (non-) obesity-attributable mortality rates. These were obtained by
25
26 136 multiplying $OAMF_{a,s}$ and $[1 - OAMF_{a,s}]$, respectively, with age- and sex-specific all-cause
27
28 137 mortality rates.

29
30
31 138 To ensure comparability across countries, over time, and between men and women,
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33
34 139 we applied direct age- and sex-standardisation (25) to obesity prevalence, obesity-
35
36 140 attributable mortality fractions, and obesity-attributable mortality rates, using the European
37
38 141 population of 2011 (26) as the standard.

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41
42 142 To assess the impact of adult obesity on e_0 , we calculated for each country the
43
44
45 143 potential gain in life expectancy (PGLE) if obesity-attributable mortality were eliminated, by
46
47 144 calendar year and sex and is in line with the approach by Preston et al. First, we calculated e_0
48
49 145 by applying standard life table techniques to age-specific all-cause mortality rates (0-
50
51 146 100)(25)). Second, we applied associated single-decrement life tables (ASDLT)(25)) to age-
52
53
54 147 and sex-specific non-obesity-attributable mortality rates (0-100) to obtain e_0 if obesity-
55
56 148 attributable mortality were eliminated. The PGLE represents the difference between the e_0
57
58 149 based on the ASDLT and the original e_0 .

1
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3 150 To summarise the changes in PGLE across countries, we estimated the average
4
5
6 151 annual changes in PGLE (in %):
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8

$$12 \quad \text{Average annual changes in PGLE (\%)} = \frac{\sum_{t=1976}^{2012} \frac{(PGLE_t - PGLE_{t-1})}{PGLE_{t-1}}}{2012 - 1975} 100$$

15
16 153 To assess the impact of obesity on time trends in e_0 between 1975 and 2012, we
17
18 154 subtracted the observed change in e_0 from the change in e_0 without obesity. The change in
19
20
21 155 e_0 without obesity was obtained by using the e_0 values from the associated single-decrement
22
23 156 life tables applied to non-obesity-attributable mortality for 1975 and 2012.
24
25

26 157 Results

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29 158 For the 26 European countries, the age-standardised obesity-attributable mortality fraction
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32 159 (OAMF) was, on average, 11% among men and 10% among women in 2012. For the USA,
33
34 160 these estimates were substantially higher; i.e., 15% and 14%, respectively. The average
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36
37 161 OAMF levels were higher in Northern, Western, and Southern Europe combined (hereafter,
38
39 162 Western Europe) than in CEE among men, while the opposite was the case among women.
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41

42 163 OAMFs were increasing over time for all countries and both sexes, although not to
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44 164 the same extent (see Figure 1, Figure S1). In Western Europe, OAMFs generally increased
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46
47 165 over the 1975-2012 period, and at a faster pace among men. In CEE, by contrast, OAMFs
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49
50 166 clearly stagnated, and even declined between 1990 and 2000. The overall increase in OAMFs
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52 167 was greatest in the USA, Ireland, Norway (men), and the UK (women).
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3 169 **Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European**
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6 170 **countries* (by 5 regions) and USA, 1975-2014, 18-100 years**
7
8

9 171 * Countries within the same region are presented with the same colour

10 172 **Central Europe:** Czech Republic, Hungary, Poland, Slovakia

11
12 173 **Eastern Europe:** Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

13
14 174 **Northern Europe:** Denmark, Finland, Iceland, Norway, Sweden

15
16 175 **Southern Europe:** Italy, Portugal, Spain

17
18 176 **Western Europe:** Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland,
19
20 177 United Kingdom

21
22 178 **USA:** United States of America

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24 179

25
26
27 180 <approximately here>

28
29
30 181 In the 26 European countries in 2012, estimates of potential gains in life expectancy at
31
32 182 birth (PGLE) if obesity was eliminated ranged from 0.86 to 1.67 years among men (1.22 on
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34 183 average) and from 0.66 to 1.54 years (0.98 on average) among women (Figure 2; Figure S2
35
36 184 and Table S2 Supplementary Material). Among men in the USA, the PGLE estimate was, at
37
38 185 1.73 years, slightly higher than the highest estimate in Europe; and among women in the
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40 186 USA, the PGLE estimate was, at 1.44 years, the second-highest after the estimate for Russia.
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42
43
44 187 The average PGLE estimate was 1.08 among men and 0.86 among women in Western
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46 188 Europe, and was 1.44 among men and 1.16 among women in CEE (see Supplementary
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48 189 Material, Table S2).

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3 191 **Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality**
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5 192 **was eliminated, in 26 European countries* (differentiating Western and Central Eastern**
6
7
8 193 **Europe) and the USA, 1975-2012**
9

10
11 194 * Countries within the same region are presented with the same colour

12
13 195 **Central Eastern Europe:** Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland,
14
15 196 Russian Federation, Slovakia, Ukraine

16
17 197 **Western Europe:** Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy,
18
19 198 Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

20
21 199 **USA:** United States of America
22

23 200

24
25
26 201 <approximately here>
27

28
29 202 Overall, from 1975 to 2012, PGLE due to obesity increased in all of the countries (Figure
30
31 203 2, Figure S2, Figure 3, 4). The increase was greater among men (average annual increase of
32
33 204 2.68%) than among women (average annual increase of 1.33%), was largest among men in
34
35 205 Portugal and Belarus and among women in Portugal, and was substantial among men and
36
37 206 women in Norway (Figures 3, 4). While there was a general increase in PGLE due to obesity,
38
39 207 this trend stagnated among women in CEE from around 1990 onwards, and levelled off after
40
41 208 1995 among women in Denmark and Switzerland.
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46
47 209 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
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49 210 **26 European countries and the USA between 1975-2012, in men**
50

51 211 <approximately here>
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56 213 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
57
58 214 **26 European countries and the USA between 1975-2012, in women**
59

60 215 <approximately here>

216 Table 1 shows the impact of obesity on time trends in life expectancy at birth (e_0).

217 Overall, the average increase in e_0 between 1975 and 2012 was 7.26 years for men and 6.28

218 years for women in the 26 European countries. Without obesity, the average increase in e_0

219 would have been 8.04 years for men and 6.58 years for women; or 0.78 and 0.30 years

220 higher, respectively. Among men, obesity had the greatest impact on e_0 trends in Lithuania

221 and the USA (more than one year), and the smallest impact in Iceland and Sweden (0.5

222 years). Among women, obesity had the greatest impact on e_0 trends in the USA and Ireland

223 (0.7 years) and the smallest impact in Estonia and the Czech Republic (less than 0.1 year).

224 **Table 1: Impact of obesity on trends in life expectancy at birth (e_0) in 26 European**

225 **countries and USA 1975-2012, by sex**

Country	Change in e_0 with obesity 2012-1975 (years)		Change in e_0 without obesity 2012-1975 (years)		Effect of obesity on e_0 change 2012-1975 (years)	
	Men	Women	Men	Women	Men	Women
	Austria	10.62	8.61	11.25	8.95	0.63
Belarus	-0.55	1.43	0.46	1.83	1.00	0.40
Belgium	8.85	7.63	9.46	7.99	0.61	0.36
Czech Republic	7.97	6.98	8.66	7.03	0.69	0.05
Denmark	6.78	5.03	7.40	5.36	0.63	0.33
Estonia	6.43	6.42	7.26	6.46	0.82	0.04
France	9.49	7.99	10.17	8.30	0.68	0.31
Finland	10.07	7.26	10.82	7.75	0.74	0.50
Hungary	5.29	6.18	6.17	6.36	0.87	0.18
Iceland	9.02	5.19	9.51	5.51	0.48	0.32
Ireland	9.40	8.40	10.22	9.10	0.83	0.69
Italy	10.19	8.56	10.81	8.89	0.62	0.33
Latvia	4.91	4.53	5.82	4.70	0.90	0.18
Lithuania	2.01	3.80	3.14	4.06	1.13	0.26
Luxembourg	11.78	9.27	12.50	9.65	0.72	0.37
Netherlands	7.68	5.10	8.26	5.6	0.56	0.49
Norway	7.70	5.33	8.42	5.86	0.74	0.51
Poland	5.90	6.74	6.81	7.00	0.91	0.27
Portugal	12.14	10.87	12.91	11.26	0.77	0.40

3	Russian Federation	2.05	2.62	3.06	2.89	1.02	0.28
4	Slovakia	5.65	5.82	6.52	6.16	0.88	0.34
5	Spain	8.82	8.75	9.62	9.14	0.79	0.39
6	Sweden	7.69	5.59	8.18	5.93	0.49	0.33
7	Switzerland	8.98	6.63	9.55	6.93	0.58	0.30
8	Ukraine	0.48	1.73	1.26	1.94	0.78	0.21
9	United Kingdom	9.46	6.96	10.20	7.55	0.74	0.59
10	USA	7.86	4.89	8.90	5.61	1.04	0.71
11	Average CEE countries	4.01	4.63	4.92	4.84	0.90	0.22
12	Average Western countries	9.10	7.09	9.76	7.50	0.66	0.41

226

227

228 Discussion

229 Summary of results

230 In the 26 European countries studied, the share of mortality due to obesity in 2012 was, on
 231 average, 11% among men and 10% among women. PGLE due to obesity in 2012 ranged from
 232 0.86 to 1.73 years among men, and from 0.66 to 1.54 years among women. Overall, PGLE
 233 increased between 1975 and 2012, albeit more quickly among men (average annual
 234 increase: 2.68%) than among women (1.33%). Among women in Denmark, Switzerland, and
 235 the CEE countries the increase in PGLE levelled off after 1995. Without obesity, the average
 236 increase in e0 between 1975 and 2012 would have been 0.78 years higher among men and
 237 0.30 years higher among women.

238 Evaluation of data and methods

239 Using the recent advances in obesity data, it is now possible to study the impact of obesity
 240 on life expectancy for a large number of countries and a long period of time. Two
 241 methodological issues warrant our attention, however.

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3 242 First, in calculating the share of mortality due to obesity (OAMF), which also forms
4
5 243 the basis for our PGLC calculations, we were hindered by limitations in the available
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8 244 prevalence and RRs data, which also affected the method used. As has previously been
9
10 245 documented, OAMF estimates are sensitive to the data and the methods used (27).

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13 246 In selecting obesity prevalence data, we used the longest validated time series based
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15 247 on population-based measurement studies that are suitable for studying the impact of
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17
18 248 obesity on long-term life expectancy trends across Europe (13). For those countries with less
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20 249 available obesity data – especially the CEE countries a portion of the data we used were
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22 250 merely the result of modelling. Thus, the resulting estimates should be treated with some
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24
25 251 caution . By contrast, for the non-CEE countries, most of the data we used pertain to
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27 252 measured data (13). Supplementary Material, Table S3 gives the confidence intervals around
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29
30 253 the age-standardised prevalence estimates for each country by sex in order, as to provide
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32 254 more information on the relative reliability of the data for the different countries in our
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34
35 255 analysis.

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37 256 Because age- and sex-specific RRs of mortality associated with obesity are not readily
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39 257 available by country and year, we have decided to apply to all of the countries studied age-
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41
42 258 and sex-specific RRs from Western European and US populations that are largely suitable for
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45 259 our setting, as had previously been done (10). Although RRs could differ slightly across
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47 260 contexts, studies that compared RRs across continents found only small differences in RRs
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50 261 between Europe and North America (7). Consequently, we do not expect to observe large
51
52 262 differences between individual countries. In addition, as time-variant European RRs were
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54 263 not available, we had to apply time-constant RRs, even though it is possible that changes in
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56
57 264 the association of obesity with mortality – which could, for example, occur because of
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59 265 improvements in the treatment of chronic diseases – have affected the impact of obesity on
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3 266 life expectancy. Previous studies that assessed changes over time in the association of
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5 267 obesity with mortality did so only for the US, and, unfortunately, provided mixed evidence,
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8 268 with some of these studies reporting a decline (18, 28, 29), and others finding an increase
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10 269 (30). Therefore, before implementing time-variant European RRs, more information on their
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12 270 direction is required. Similarly, comparable country-specific RRs are urgently needed. In
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14 271 addition, the choice of these RRs along with their reference group might exert an effect in
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16 272 our estimates. Based on the available data, only a fairly simple – albeit common applied –
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18 273 the weighted sum method could be applied (27) to estimate the OAMFs. The application of a
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20 274 more advanced methodology (27) could have affected the OAMFs and thus the PGLE levels,
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22 275 but less the trends(31). The lack of information on the uncertainty of the RRs we used
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24 276 limited us in estimating confidence intervals for the OAMFs and PGLEs.

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29 277 Second, besides being the result of the OAMFs, the PGLE estimates can also be
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31 278 affected by all-cause mortality levels and trends as age- and sex-specific all-cause mortality
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33 279 rates are used to estimate PGLE. Since all-cause mortality fluctuated greatly in CEE in the
34
35 280 analysed period (12), short-term variations in PGLE in CEE countries should be treated with
36
37 281 more caution.

282 **Explanation of results**

283 In 2012, the PGLE due to obesity were, on average, 1.22 years for men and 0.98
284 years for women in the 26 European countries, and 1.73 years for men and 1.43 years for
285 women in the USA. A comparison of our 2006 e50 estimates with those of Preston et al. (10)
286 for the same countries uncovered only small differences, except among men in the USA (our
287 estimate was 0.56 years lower) and women in the UK (our estimate was 0.29 years lower)
288 (see Supplementary Material, Table S4). Given that approximately the same methodology
289 was used to estimate the OAMFs, the observed differences are most likely due to the use of

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3 290 different obesity prevalence and RRs data. Preston used prevalence data from national
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5 291 representative surveys and RRs from the Prospective Studies collaboration (10). Given that
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7
8 292 the observed differences do not have the same direction for the different countries, we
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10 293 believe that these differences are mainly attributable to the prevalence data used. To
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12 294 further evaluate our observed PGLE levels, we compared them with own PGLE estimates for
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14 295 smoking and alcohol (32). Our PGLE estimates for smoking were 2.38 years for men and 1.00
15
16 296 year for women in Western Europe, and 3.82 years for men and 0.67 years for women in
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18 297 CEE. Our PGLE estimates for alcohol were 0.90 years for men and 0.44 years for women in
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20 298 Western Europe, and 2.15 years for men and 1.00 year for women in CEE (32) while our
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22 299 average PGLE for obesity was 1.08 among men and 0.86 among women in Western Europe,
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24 300 and 1.44 among men and 1.16 among women in CEE. Thus, obesity's impact on life
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26 301 expectancy lies between that of smoking and alcohol, and can be considered significant.
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33 302 In our study, we found that PGLE due to obesity was increasing, but that this trend
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35 303 differed across countries and between the sexes. This overall trend can be explained by the
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37 304 general increase in obesity prevalence in European countries (see Supplementary Material,
38
39 305 Figure S3) (13) and the resulting growth in the burden of obesity (3), which is also reflected
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41 306 in the OAMFs (Figure 1, Figure S1) in these countries.
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46 307 At the same time, parts of the observed variation in the increase in PGLE estimates
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48 308 across the USA, Western Europe, and CEE and between the sexes reflect differences in the
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50 309 onset, the development, and the impact of the obesity epidemic in these countries and in
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52 310 men and women. Across the countries studied, the absolute increase in PGLE was largest
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54 311 among women and second-largest among men in the USA. This pattern is in line with
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56 312 evidence showing that between 1980 and 2008, obesity increased much more in the USA
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3 313 than in Europe(1, 33). This rapid progression of the obesity epidemic in the USA and its large
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5 314 impact on life expectancy has been attributed to an increasingly obesogenic environment
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8 315 caused by factors such as changes in food preparation and processes that promote the
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10 316 consumption of calorically dense foods, and a pronounced decrease in physical activity levels
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13 317 (34). The obesity epidemic has progressed more slowly in Western Europe than in the USA(1,
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15 318 13). However, obesity levels in countries like the UK and Ireland are rapidly approaching
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18 319 those in the USA (35), as our PGLLE estimates also show.

21 320 In the CEE countries, the PGLLE trends track the evolution of the obesity epidemic in
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23 321 that region (see Supplementary Material, Figure S3). Obesity levels have been higher in CEE
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25 322 than in Western Europe since 1980 (36, 37), which suggests that the epidemic started earlier
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27
28 323 in CEE. As a result of this earlier onset, the impact of obesity (as expressed in terms of OAMF
29
30 324 and PGLLE) in the 1970s and 1980s was at times even greater in CEE than in the USA,
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32
33 325 especially among women. While there are many potential explanations for this early onset
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35 326 of the obesity epidemic in CEE, the available data indicate that the main factors were the
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37
38 327 relatively high total energy supply and energy intake in CEE in those years (38).

41 328 The overall progress of the obesity epidemic was lower in CEE than in Western
42
43 329 Europe, and the increase was not constant (1). Indeed, in CEE, increases in obesity
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45 330 prevalence(1, 39), OAMFs, and PGLLE stagnated in the 1980-2008 period, and were more
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48 331 pronounced in the 1990s (1, 39). However, as these countries started the study period with
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50 332 higher obesity prevalence levels, these trends resulted in the CEE having higher average
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53 333 PGLLE levels than the West. The pattern of stagnation observed in the CEE, could be
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56 334 explained by the decrease in energy supplies at the beginning of the 1990s in CEE (37)
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58 335 resulting from the dramatic economic and political changes in those countries (3, 36, 39) and
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3 336 which in turn affected the socio-economic status of the population (SES). Among CEE
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6 337 women, the increase in obesity starting in the 1990s was smaller than it was in the previous
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8 338 period, and was smaller than it was among CEE men. The lower risk of obesity observed
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10 339 among women than among men with low socioeconomic status (SES) in low-income
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13 340 countries (40) may explain this difference.

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16 341 In Western Europe, a stagnation in PGLLE levels was observed among women in
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18 342 Denmark and Switzerland after 1995. This finding seems to be in line with studies reporting a
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20 343 levelling-off of mean BMI since the 1990s (41); and in specific sub-populations, such as
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22 344 adults with high SES in regions within Switzerland, Italy, France, and Finland
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24
25 345 (37). Although dietary and physical activity information is spreading equally across
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27 346 socioeconomic groups, those with higher SES have a greater ability and capacity to adopt a
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29 347 healthier dietary and physical activity pattern (42). In addition, it appears that higher SES
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31 348 women in particular are more health-conscious, have healthier food habits, and are more
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33 349 prone to follow nutritional recommendations (43) as they are under greater social pressure
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35 350 to be thin (44). Similarly, countries with higher income levels and lower levels of inequality
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37 351 (45), like Switzerland and Denmark, tend to have lower obesity levels, especially among
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43 352 women.

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46 353 When we considered the impact of obesity on life expectancy in the 26 European
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48 354 countries, we found that without obesity, the increase in e0 between 1975 and 2012 would
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50 355 have been, on average, 0.78 years higher among men and 0.30 years higher among women.
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52 356 These figures account for approximately 10% of the average change in e0 between 1975 and
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54 357 2012 among men, and 5% among women. It is therefore clear that the impact of obesity on
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56 358 changes in e0 should not be ignored. Moreover, the impact of obesity on life expectancy
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3 359 levels and on life expectancy trends is likely to increase, as previous studies have also
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5 360 suggested (8). There are several indicators pointing in that direction, including evidence that
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8 361 obesity's impact is already substantially greater in the USA (13% among men and 15%
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10 362 among women) than elsewhere; obesity prevalence is increasing rapidly in most European
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12 363 countries (see Supplementary Material, Figure S3); obesity is increasing in severity; and the
13
14
15 364 duration of obesity is rising in younger generations (8).

365 **Conclusion and implications**

366 Obesity was proven to have an impact on both life expectancy levels and trends in
367 Europe. The observed differences in the increase in the impact of obesity across countries
368 and between the sexes reflect differences in the onset and the progression of the obesity
369 epidemic, and can be linked to contextual factors (economic conditions, obesogenic
370 environment, energy supplies), as well as to differences in people's ability and capacity to
371 adopt healthier lifestyles.

372 It is likely that in the future obesity will have a larger impact on mortality and life
373 expectancy in Europe, as obesity prevalence and obesity-attributable mortality continue to
374 increase in the majority of countries. These trends will have important health, economic,
375 and social implications. Specifically, the increasing prevalence of obesity among European
376 populations, and especially at younger ages, will lead to an increased prevalence of obesity-
377 related disorders, as well as to increases in the mortality burden associated with obesity and
378 in obesity's effects on life expectancy and quality of life. Thus, obesity will constitute an
379 additional burden for societies, economies, and public health. It is therefore crucial that
380 effective public health initiatives are undertaken to tackle the obesity epidemic and its
381 effects on public health. Such initiatives should address the multifactorial and complex

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3 382 obesity aetiology; the clear differences between countries and the sexes; as well as the
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5 383 factors underlying these differences, such as contextual factors and differences in
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8 384 individuals' ability and capacity to adopt healthier lifestyles.
9

10 11 385 **Funding** 12

13
14 386 This work was supported by the Netherlands Organisation for Scientific Research (NWO) in
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16 387 connection with the research programme "Smoking, alcohol, and obesity, ingredients for
17
18 388 improved and robust mortality projections, grant no. 452-13-001; see
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20 389 www.futuremortality.com.
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26 27 28 391 **Conflict of Interest** 29

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31 392 None declared.
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36 37 38 394 **Author contribution** 39

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42 395 N.Vidra contributed to the conception and design of the work; to the acquisition, analysis,
43
44 396 and interpretation of data for the work; drafted and revised the work critically for important
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46 397 intellectual content; approved the final version of the work to be published and agrees to be
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48 398 accountable for all aspects of the work in ensuring that questions related to the accuracy or
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50 399 integrity of any part of the work are appropriately investigated and resolved.
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55 400 S. Trias-Llimós contributed to the analysis, and interpretation of data for the work; revised it
56
57 401 critically for important intellectual content; approved the final version of the work to be
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11 405 F. Janssen contributed to the conception and design of the work; to the interpretation of
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13 406 data for the work; revised the work critically for important intellectual content; approved
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15 407 the final version of the work to be published and agrees to be accountable for all aspects of
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17 408 the work in ensuring that questions related to the accuracy or integrity of any part of the
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23 24 25 410 **Data statement**

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28 411 Obesity prevalence data can be obtained from NCD Risk Factor Collaboration (NCD-RisC)
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30 412 (www.ncdrisc.org).
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34 413 All-cause mortality and exposure population data can be obtained from the Human
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36 414 Mortality Database (<http://www.mortality.org>).
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58 422 robust mortality projections, grant no. 452-13-001. See www.futuremortality.com
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910 425 **References**

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3 543 **Figure legends**
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5 544 **Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European**
6 **countries* (by 5 regions) and USA, 1975-2014, 18-100 years**
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11 547 * Countries within the same region are presented with the same colour

12
13 548 **Central Europe:** Czech Republic, Hungary, Poland, Slovakia

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15 549 **Eastern Europe:** Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

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17 550 **Northern Europe:** Denmark, Finland, Iceland, Norway, Sweden

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19 551 **Southern Europe:** Italy, Portugal, Spain

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21 552 **Western Europe:** Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland,
22 United Kingdom

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24 554 **USA:** United States of America

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28 556 **Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality**
29 **was eliminated, in 26 European countries* (differentiating Western and Central Eastern**
30 **Europe) and the USA, 1975-2012, 18-100 years**
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38 561 **Central Eastern Europe:** Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland,
39 Russian Federation, Slovakia, Ukraine

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41 563 **Western Europe:** Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy,
42 Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

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44 564 **USA:** United States of America

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50 567 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
51 **26 European countries and the USA between 1975-2012, in men**
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55 570 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
56 **26 European countries and the USA between 1975-2012, in women**
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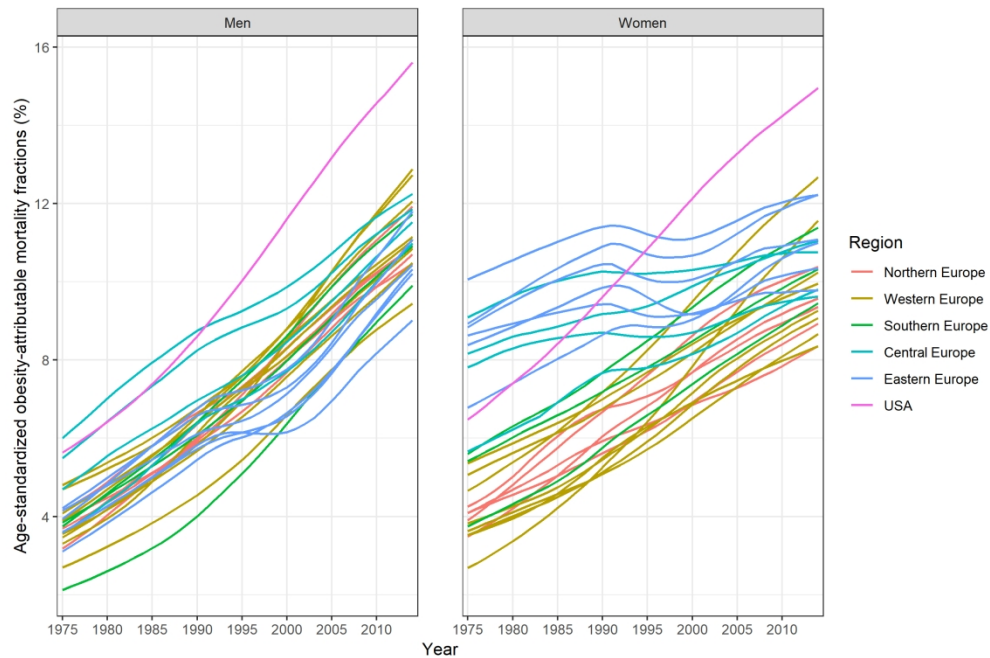


Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European countries* (by 5 regions) and USA, 1975-2014, 18-100 years

* Countries within the same region are presented with the same colour

Central Europe: Czech Republic, Hungary, Poland, Slovakia

Eastern Europe: Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

Northern Europe: Denmark, Finland, Iceland, Norway, Sweden

Southern Europe: Italy, Portugal, Spain

Western Europe: Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom

USA: United States of America

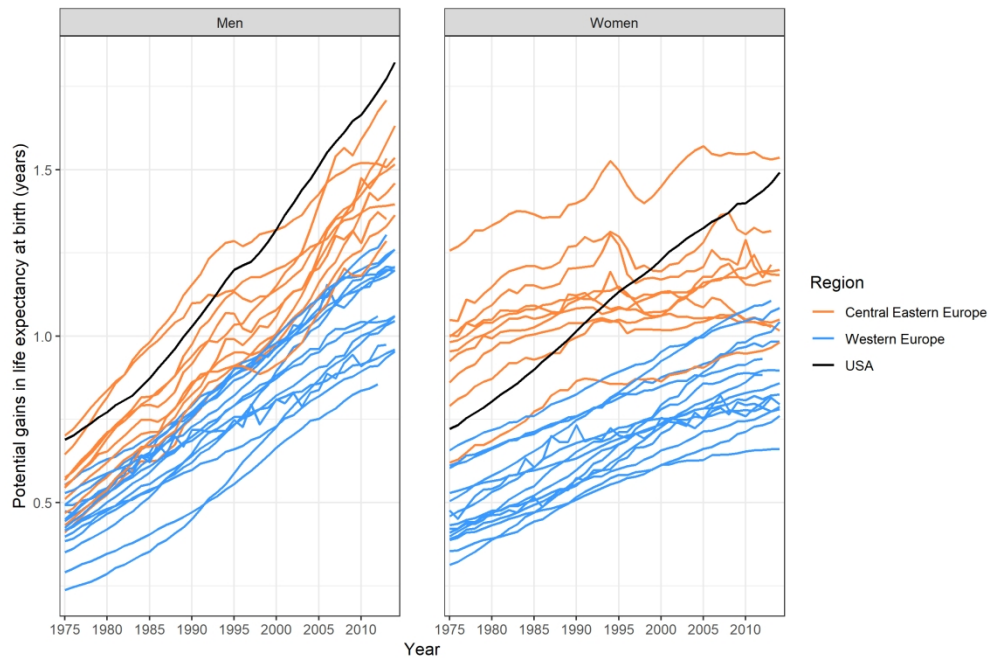


Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries* (differentiating Western and Central Eastern Europe) and the USA, 1975-2012

* Countries within the same region are presented with the same colour

Central Eastern Europe: Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Ukraine

Western Europe: Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

USA: United States of America

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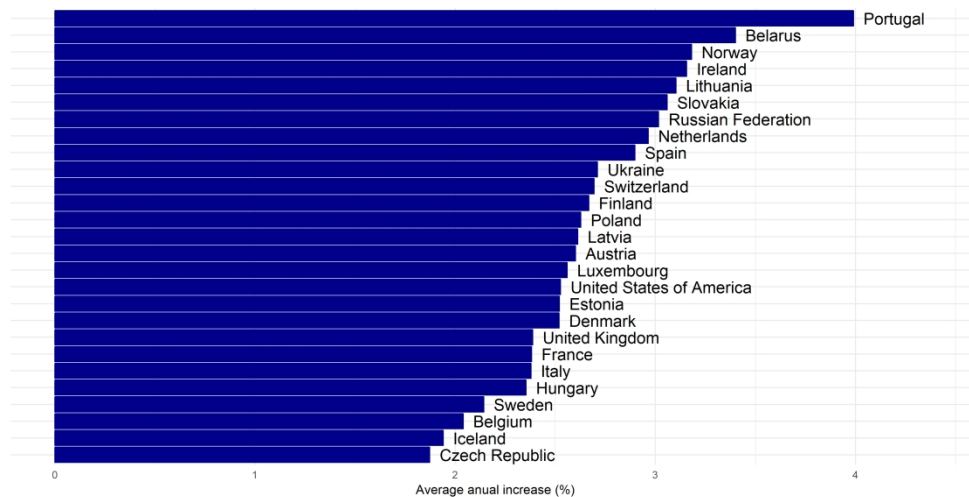


Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in men

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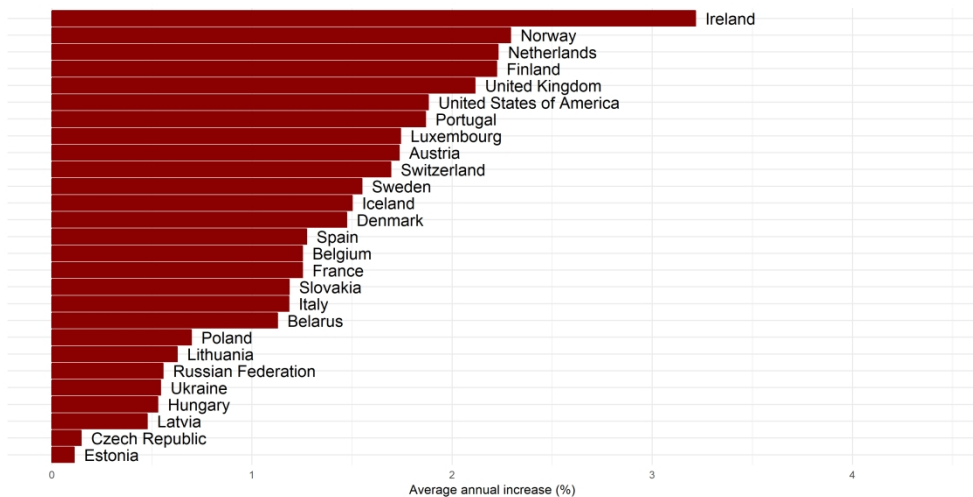


Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in women

Impact of obesity on life expectancy among different European countries, 1975-2012

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Supplementary material

Table S1: Age-and sex-specific RRs of dying from obesity from the meta-review from Lobstein et al. (2010)

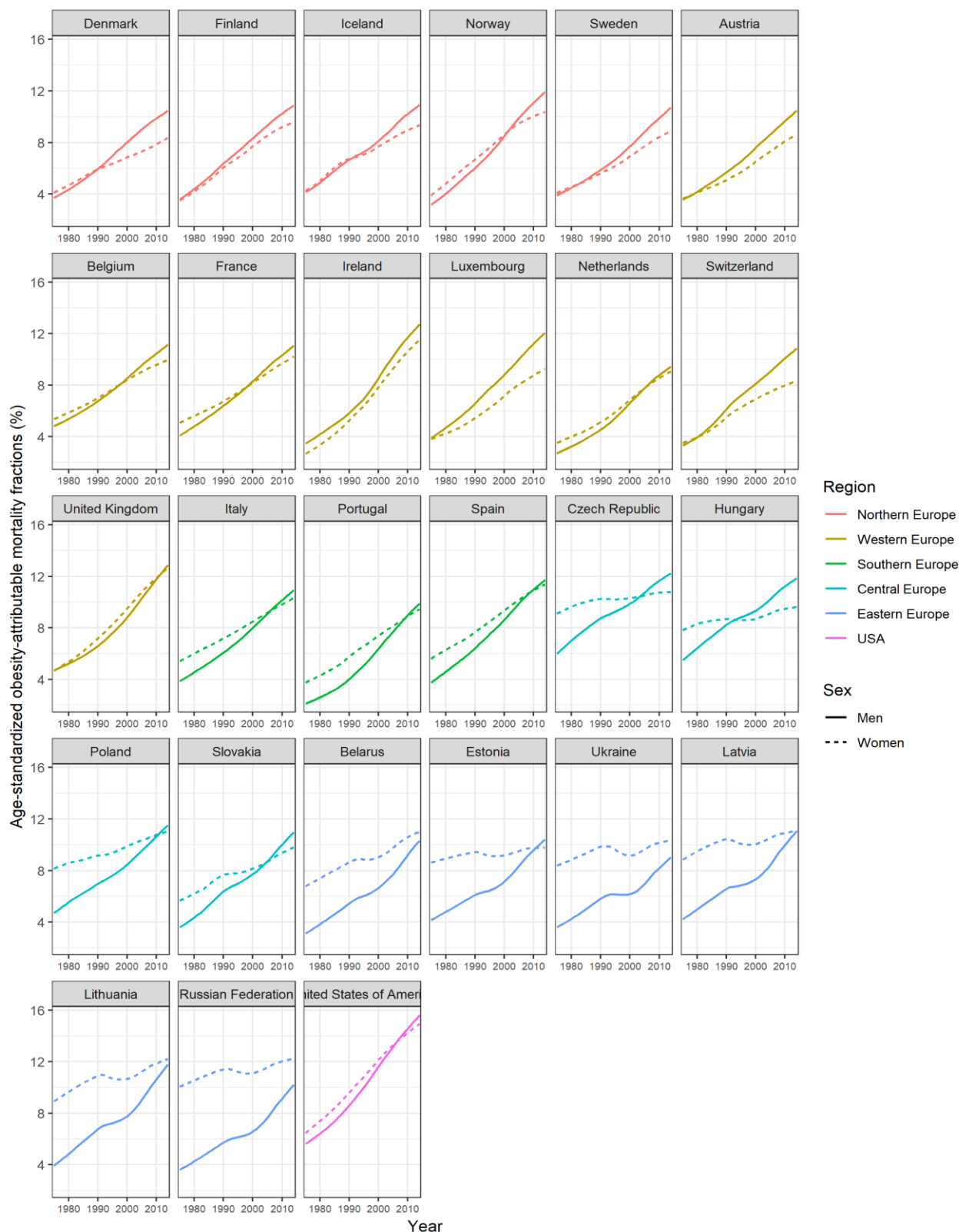
Age	RR*	
	Men	Women
<50	1.55	1.5
50-59	1.539	1.49
60-69	1.5225	1.475
70+	1.495	1.45

*Reference group for the RRs: normal weight ($18.5 \leq \text{BMI} \leq 24.9 \text{ kg/m}^2$)

Table S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, in 1975 and 2012, 18-100 years

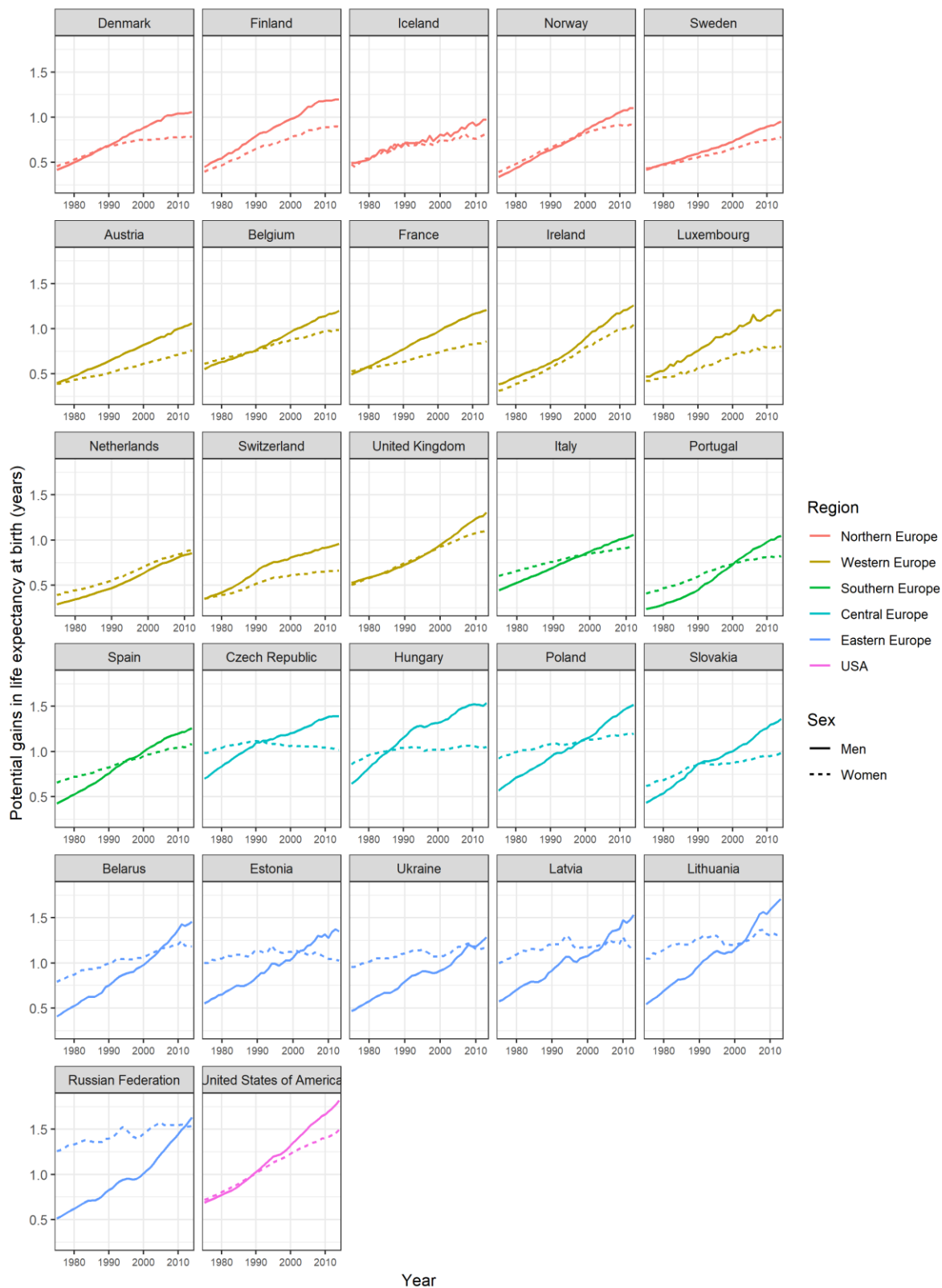
Country	PGL 1975		PGL 2012	
	Men	Women	Men	Women
Central Eastern Europe (CEE)				
Belarus	0.41	0.79	1.41	1.19
Czech Republic	0.70	0.98	1.39	1.03
Estonia	0.55	1.00	1.37	1.04
Hungary	0.64	0.86	1.52	1.04
Latvia	0.58	1.00	1.48	1.18
Lithuania	0.54	1.05	1.67	1.31
Poland	0.57	0.93	1.48	1.19
Russian Federation	0.51	1.26	1.53	1.54
Slovakia	0.43	0.62	1.31	0.96
Ukraine	0.47	0.95	1.25	1.16
Average CEE	0.54	0.94	1.44	1.16
Western Europe				
Austria	0.40	0.39	1.03	0.73
Belgium	0.55	0.61	1.17	0.97
Denmark	0.42	0.46	1.04	0.79
France	0.49	0.53	1.18	0.84
Finland	0.45	0.40	1.19	0.90
Ireland	0.38	0.31	1.21	1.01
Iceland	0.49	0.48	0.97	0.80
Italy	0.44	0.60	1.06	0.93
Luxembourg	0.47	0.42	1.19	0.79
Netherlands	0.29	0.39	0.86	0.88
Norway	0.34	0.39	1.07	0.91
Portugal	0.24	0.41	1.01	0.81
Spain	0.42	0.66	1.22	1.05
Sweden	0.42	0.43	0.91	0.76
Switzerland	0.35	0.35	0.93	0.66
United Kingdom	0.53	0.50	1.27	1.09
Average Western Europe	0.41	0.48	1.08	0.86
USA	0.69	0.72	1.73	1.44
Average European countries	0.46	0.64	1.22	0.98
Average all countries	0.47	0.64	1.23	1.00

Figure S1: Age-standardised obesity-attributable mortality fractions in 26 European countries*, grouped by 5 regions and USA, 1975-2014, 18-100 years



* Countries within the same region are presented with the same colour

Figure S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries*, grouped by 5 regions and USA, 1975-2012, 18-100 years



* Countries within the same region are presented with the same colour

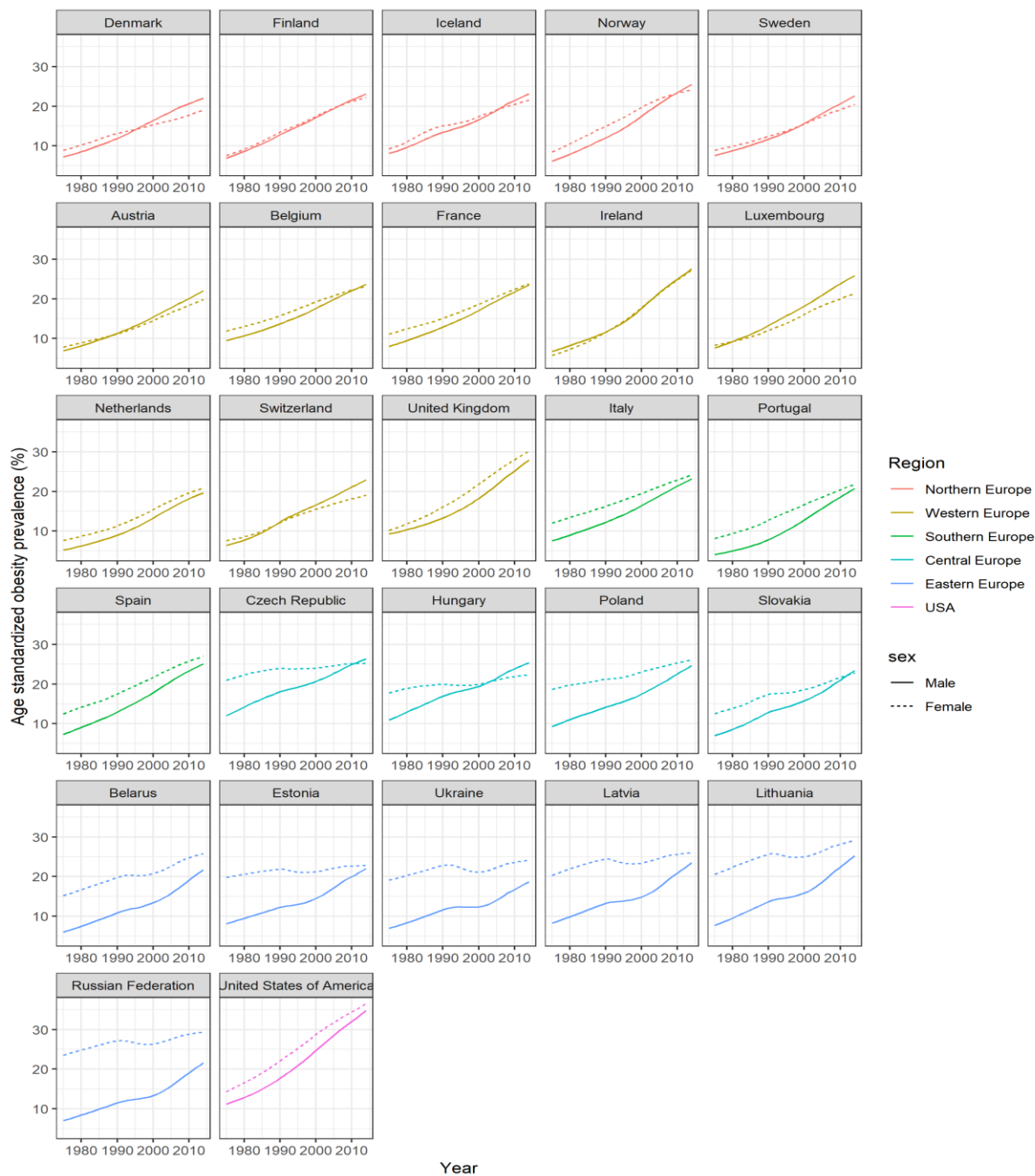
Table S3: Age-standardised obesity prevalence and 95% confidence intervals, in 26 European countries (differentiating Western and Central Eastern Europe) and USA, 18-100 years in 2012.

Country	Age-standardised (stand.) obesity prevalence (%)			
	Age-stand.	95% confidence intervals	Age-stand.	95% confidence intervals
	Men		Women	
Central Eastern Europe				
Belarus	20.4	13.6; 28.5	25.4	17.7; 34.1
Czech Republic	25.6	18.9; 33.4	25.2	18.3; 33.0
Estonia	21.0	16.0; 26.8	22.7	17.4; 28.8
Hungary	24.6	17.9; 32.0	22.1	15.4; 29.8
Latvia	22.2	15.2; 30.2	25.8	18.4; 34.5
Lithuania	23.8	16.9; 31.8	28.7	21.2; 37.1
Poland	23.6	18.0; 29.7	25.7	19.5; 32.5
Russian Federation	20.4	14.8; 26.8	29.1	22.6; 36.2
Slovakia	22.2	15.7; 29.6	22.2	15.8; 29.6
Ukraine	17.7	11.2; 25.7	23.9	16.3; 32.5
Western Europe				
Austria	21.1	14.7; 28.2	19.1	13.4; 25.5
Belgium	22.9	17.3; 29.1	22.7	17.1; 28.9
Denmark	21.3	15.5; 27.9	18.4	13.1; 24.5
France	22.6	16.3; 29.6	23.1	16.9; 29.9
Finland	22.3	17.1; 28.2	21.7	16.7; 27.3
Ireland	26.2	19.4; 33.8	26.0	19.5; 33.2
Iceland	22.3	15.6; 29.8	21.0	14.7; 28.3
Italy	22.3	17.0; 28.1	23.5	18.1; 29.6
Luxembourg	24.9	17.6; 32.9	20.7	14.3; 28.0
Netherlands	18.9	13.8; 24.5	20.3	15.3; 25.8
Norway	24.5	18.5; 31.2	23.7	18.0; 30.2
Portugal	19.6	13.8; 26.4	21.1	15.0; 28.1
Spain	24.2	18.5; 30.5	26.4	20.3; 32.8
Sweden	21.6	16.3; 27.4	19.8	14.7; 25.6
Switzerland	22.0	16.3; 28.3	18.6	13.1; 24.8
United Kingdom	26.5	22.3; 31.2	29.1	24.8; 33.6
USA	33.4	27.5; 39.5	35.5	29.7; 41.5

Table S4: Potential gains in life expectancy at age 50 (PGL e50) if obesity-attributable mortality was eliminated, own estimates and those by Preston et al.2011, in the same countries studied, in 2006

Country	PGL e50 2006, own estimates	PGL e50 2006, Preston's estimates	Difference
Men			
Austria	0.81	1.00	-0.19
Belgium	0.95	0.98	-0.03
Czech Republic	1.14	1.34	-0.20
Denmark	0.88	0.82	0.06
France	0.94	0.99	-0.05
Italy	0.88	0.90	-0.02
Netherlands	0.69	0.73	-0.04
Poland	1.14	1.37	-0.23
Spain	1.02	1.15	-0.13
Sweden	0.75	0.72	0.03
Switzerland	0.77	0.79	-0.02
United Kingdom	0.99	1.34	-0.35
USA	1.29	1.85	-0.56
Women			
Austria	0.62	0.71	-0.09
Belgium	0.86	0.73	0.13
Czech Republic	0.87	1.01	-0.14
Denmark	0.71	0.62	0.09
France	0.72	0.52	0.2
Italy	0.84	0.57	0.27
Netherlands	0.76	0.69	0.07
Poland	1.08	1.19	-0.11
Spain	0.95	0.87	0.08
Sweden	0.67	0.63	0.04
Switzerland	0.59	0.50	0.09
United Kingdom	0.94	1.23	-0.29
USA	1.18	1.28	-0.10

Figure S3: Age-standardised obesity prevalence in 26 European countries*, grouped by 5 regions and USA, 1975-2012, 18-100 years



* Countries within the same region are presented with the same colour

BMJ Open

Impact of obesity on life expectancy among different European countries: secondary analysis of population-level data over the 1975-2012 period

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3 1 **Impact of obesity on life expectancy among different European countries: secondary**
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5 2 **analysis of population-level data over the 1975-2012 period**
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59 20 **Word count: 3669 words**
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6 22**Abstract**

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9 23 **Objective:** This study assesses the impact of obesity on life expectancy for 26 European
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12 24 national populations and the USA over the 1975-2012 period.

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15 25 **Design:** Secondary analysis of population-level obesity and mortality data.

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18 26 **Setting:** European countries, namely Austria, Belarus, Belgium, the Czech Republic,
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21 27 Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania,
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23 28 Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia,
24
25 29 Spain, Sweden, Switzerland, Ukraine, the United Kingdom (UK); and the USA.

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27
28 30 **Participants:** National populations aged 18–100 years, by sex.

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31 31 **Measurements:** Using data by age and sex, we calculated obesity-attributable mortality by
32
33 32 multiplying all-cause mortality (Human Mortality Database) with obesity-attributable
34
35 33 mortality fractions (OAMFs). OAMFs were obtained by applying the weighted-sum method
36
37 34 to obesity prevalence data (NCD Risk Factor Collaboration) and European Relative Risks (RRs)
38
39 35 (DYNAMO). We estimated potential gains in life expectancy at birth (PGLE) by eliminating
40
41 36 obesity-attributable mortality from all-cause mortality using associated single-decrement life
42
43 37 tables.

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45
46 38 **Results:** In the 26 European countries in 2012, PGLE due to obesity ranged from 0.86 to 1.67
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48 39 years among men, and from 0.66 to 1.54 years among women. In all countries, PGLE
49
50 40 increased over time, with an average annual increase of 2.68% among men and 1.33% and
51
52 41 among women. Among women in Denmark, Switzerland, and Central and Eastern European
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54 42 countries, the increase in PGLE levelled off after 1995. Without obesity, the average increase
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3 43 in life expectancy between 1975 and 2012 would have been 0.78 years higher among men
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6 44 and 0.30 years higher among women.
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9 45 **Conclusions:** Obesity was proven to have an impact on both life expectancy levels and
10
11 46 trends in Europe. The differences found in this impact between countries and the sexes can
12
13 47 be linked to contextual factors, as well as to differences in people's ability and capacity to
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15
16 48 adopt healthier lifestyles.
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19 49 **Keywords:** Obesity, life expectancy, Europe, USA
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21

22 23 50 **Article Summary**

24 25 26 51 **Strengths and limitations of the study**

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28
29 52 • This is the first study to assess the impact of obesity on life expectancy at birth over
30
31 53 time, and we do so here for 26 European countries and the USA.
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34 54 • We used recent long-term comparable data on obesity prevalence based on
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37 55 population-based measurement studies, and European relative risks of dying from obesity by
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39 56 age and sex from a recent meta-analysis.
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42 57 • Because of remaining data limitations regarding prevalence and relative risks, we had
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45 58 to use a fairly simple – albeit common applied - methodology to estimate obesity-
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47 59 attributable mortality.
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64 Introduction

65 Obesity is a global epidemic (1), with Europe currently ranking second worldwide after the
66 USA (2). Over the last 20 years obesity prevalence has increased threefold in Europe(3),
67 although not uniformly across countries (4). Estimates for 2014 indicate that obesity varied
68 threefold across European countries, ranging from a low of 9% in Romania to a high of 26%
69 in Malta (5). Obesity constitutes a serious health burden at the individual and population
70 levels because it is associated with an increased risk of morbidity (6), and mortality (7).
71 However, the potential impact of the increase in obesity on life expectancy trends remains
72 largely unknown (8).

73 The few existing studies that assessed the impact of obesity on life expectancy at the
74 population level provided estimates at one specific point in time only (9, 10). Olshansky et al.
75 found that if obesity was eliminated, life expectancy at birth (e_0) in the USA in 2000 would
76 be 0.21 to 1.08 years higher, depending on gender and ethnicity (9). Preston et al. (10)
77 estimated for 16 low-mortality countries in 2006 that the reduction in life expectancy at age
78 50 (e_{50}) due to obesity was greatest in the USA, at more than 1.5 years; and ranged from
79 0.50 to 1.19 years for women and from 0.72 to 1.37 years for men in European countries.

80 Gaining insight into the impact of obesity on trends in life expectancy is especially
81 relevant (11) given the marked differences in life expectancy trends across Europe (12). In
82 Western European countries, e_0 has been increasing steadily, and has risen six to eight years
83 since 1970. But in Central and Eastern Europe (CEE), e_0 stagnated or even declined between
84 the 1970s and the 1980s, and did not start increasing again until the 1990s. There are also
85 marked differences in e_0 trends between individual European countries (12).

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3 86 In light of these important differences between European countries in both obesity
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5 87 prevalence and life expectancy over time, our aim is to assess the impact of obesity on long-
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8 88 term trends in life expectancy across a wide range of European countries.
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11 89 Our sole focus is on the impact of obesity, given the significant health burden caused by
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13 90 obesity, the large body of literature on its impact, and the well-documented association of
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16 91 obesity with mortality.
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18 19 92 **Data and Methods**

20 21 22 93 **Setting**

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25 94 We studied the impact of obesity on life expectancy by sex over the 1975-2012 period in 26
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27 95 European countries: Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia,
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29 96 Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the
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31 97 Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden,
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33 98 Switzerland, Ukraine, the United Kingdom (UK); and the USA as a comparison country (10).
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38 99 **Data**

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41 100 Long-term comparable obesity prevalence data ($BMI \geq 30 \text{ kg/m}^2$) by country, sex, age (18-19,
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43 101 20-24, ..., 85+), and year (1975-2012), based on 1698 population-based measurement studies,
44
45 102 were obtained from the NCD Risk Factor Collaboration study (13). These validated data
46
47 103 comprise the available measured height and weight data of 19.2 million participants from
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49 104 representative data sources, supplemented with estimates based on information from other
50
51 105 years and related countries from a Bayesian hierarchical model (13). The same model was
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53 106 applied to all countries and used as an input the measured weight and height data, including
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56 107 covariates that help predict BMI (13).
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3 108 The age- (<50, 50-59, 60-69 and ≥ 70 years) and sex-specific relative risks (RRs) of
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6 109 dying from obesity (see Supplementary Material Table S1) came from a review of studies
7
8 110 mainly conducted in Western Europe and the USA, with the normal-weight category used as
9
10 111 the reference group ($18.5 \leq \text{BMI} \leq 25 \text{ kg/m}^2$) (14). These age- and sex-specific RRs were largely
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12
13 112 in line with the overall European RR of 1.64 recently estimated by the Global BMI Mortality
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15 113 Collaboration (7). The differences across age groups found in that study were similar with
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17
18 114 those reported in our findings (i.e., higher RRs at younger than at older ages), though they
19
20 115 were less distinct (7). In addition, the use of RRs with the normal weight category as the
21
22
23 116 reference category is in line with previous studies that estimated obesity-attributable
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25 117 mortality (15-19), while the estimation of obesity-attributable mortality with such a RR can
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28 118 be considered the theoretically maximally possible attributable mortality (20).

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31 119 All-cause mortality numbers and exposure population data by single year of age, sex,
32
33 120 year, and country were obtained from the Human Mortality Database (21). These data are of
34
35
36 121 high quality and are widely used within the demographic community and beyond (22).

37 38 39 122 **Patient and Public Involvement**

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42 123 No patients were involved in this study.

43 44 45 124 **Methods**

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49 125 We performed our analyses separately by country and sex, based on data by single year of
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51 126 age (18-100). The obesity prevalence data were turned into single-age prevalence (18-100)
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54 127 by applying Loess smoothing (23). The RRs were turned into single-year RRs (18- 100) using
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56 128 linear regression.

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3 129 To estimate the obesity-attributable mortality fraction (OAMF) – i.e., the share of all-
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6 130 cause mortality due to obesity – we used the Rockhill formula to estimate OAMFs by age (a)
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8 131 and sex (s) (24).

$$11 \quad 132 \quad OAMF_{a,s} = \frac{P_{a,s} \cdot (RR_{a,s} - 1)}{1 + (P_{a,s} \cdot (RR_{a,s} - 1))} \text{(Equation 1)}$$

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16 133 where P is the obesity prevalence. We then weighted the $OAMF_{a,s}$ with the corresponding
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18 134 number of deaths.

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21 135 For the estimation of the impact of obesity on life expectancy (see 2.3.2) we needed
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24 136 age-and sex-specific (non-) obesity-attributable mortality rates. These were obtained by
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26 137 multiplying $OAMF_{a,s}$ and $[1 - OAMF_{a,s}]$, respectively, with age- and sex-specific all-cause
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28 138 mortality rates.

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31 139 To ensure comparability across countries, over time, and between men and women,
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34 140 we applied direct age- and sex-standardisation (25) to obesity prevalence, obesity-
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36 141 attributable mortality fractions, and obesity-attributable mortality rates, using the European
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38 142 population of 2011 (26) as the standard.

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42 143 To assess the impact of adult obesity on e_0 , we calculated for each country the
43
44 144 potential gain in life expectancy (PGLE) if obesity-attributable mortality were eliminated, by
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46 145 calendar year and sex and is in line with the approach by Preston et al. First, we calculated e_0
47
48 146 by applying standard life table techniques to age-specific all-cause mortality rates (0-
49
50 147 100)(25)). Second, we applied associated single-decrement life tables (ASDLT)(25)) to age-
51
52 148 and sex-specific non-obesity-attributable mortality rates (0-100) to obtain e_0 if obesity-
53
54 149 attributable mortality were eliminated. The PGLE represents the difference between the e_0
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56 150 based on the ASDLT and the original e_0 .

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3 151 To summarise the changes in PGLE across countries, we estimated the average
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6 152 annual changes in PGLE (in %):
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$$\text{Average annual changes in PGLE (\%)} = \frac{\sum_{t=1976}^{2012} \frac{(PGLE_t - PGLE_{t-1})}{PGLE_{t-1}}}{2012 - 1975} 100$$

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16 154 To assess the impact of obesity on time trends in e_0 between 1975 and 2012, we
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18 155 subtracted the observed change in e_0 from the change in e_0 without obesity. The change in
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21 156 e_0 without obesity was obtained by using the e_0 values from the associated single-decrement
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23 157 life tables applied to non-obesity-attributable mortality for 1975 and 2012.
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26 158 **Results**

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29 159 For the 26 European countries, the age-standardised obesity-attributable mortality fraction
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32 160 (OAMF) was, on average, 11% among men and 10% among women in 2012. For the USA,
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34 161 these estimates were substantially higher; i.e., 15% and 14%, respectively. The average
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37 162 OAMF levels were higher in Northern, Western, and Southern Europe combined (hereafter,
38
39 163 Western Europe) than in CEE among men, while the opposite was the case among women.
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42 164 OAMFs were increasing over time for all countries and both sexes, although not to
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45 165 the same extent (see Figure 1, Figure S1). In Western Europe, OAMFs generally increased
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47 166 over the 1975-2012 period, and at a faster pace among men. In CEE, by contrast, OAMFs
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50 167 clearly stagnated, and even declined between 1990 and 2000. The overall increase in OAMFs
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52 168 was greatest in the USA, Ireland, Norway (men), and the UK (women).
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3 170 **Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European**
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5 171 **countries* (by 5 regions) and USA, 1975-2014, 18-100 years**

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9 172 * Countries within the same region are presented with the same colour

10 173 **Central Europe:** Czech Republic, Hungary, Poland, Slovakia

11
12 174 **Eastern Europe:** Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

13
14 175 **Northern Europe:** Denmark, Finland, Iceland, Norway, Sweden

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16 176 **Southern Europe:** Italy, Portugal, Spain

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18 177 **Western Europe:** Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland,
19
20 178 United Kingdom

21 179 **USA:** United States of America

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27 181 <approximately here>

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30 182 In the 26 European countries in 2012, estimates of potential gains in life expectancy at
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32 183 birth (PGLE) if obesity was eliminated ranged from 0.86 to 1.67 years among men (1.22 on
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34 184 average) and from 0.66 to 1.54 years (0.98 on average) among women (Figure 2; Figure S2
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36 185 and Table S2 Supplementary Material). Among men in the USA, the PGLE estimate was, at
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38 186 1.73 years, slightly higher than the highest estimate in Europe; and among women in the
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40 187 USA, the PGLE estimate was, at 1.44 years, the second-highest after the estimate for Russia.
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44 188 The average PGLE estimate was 1.08 among men and 0.86 among women in Western
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46 189 Europe, and was 1.44 among men and 1.16 among women in CEE (see Supplementary
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49 190 Material, Table S2).

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3 192 **Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality**
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5 193 **was eliminated, in 26 European countries* (differentiating Western and Central Eastern**
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8 194 **Europe) and the USA, 1975-2012**
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11 195 * Countries within the same region are presented with the same colour

12
13 196 **Central Eastern Europe:** Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland,
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15 197 Russian Federation, Slovakia, Ukraine

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17 198 **Western Europe:** Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy,
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19 199 Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

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21 200 **USA:** United States of America
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26 202 <approximately here>
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28
29 203 Overall, from 1975 to 2012, PGLE due to obesity increased in all of the countries (Figure
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31 204 2, Figure S2, Figure 3, 4). The increase was greater among men (average annual increase of
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33 205 2.68%) than among women (average annual increase of 1.33%), was largest among men in
34
35 206 Portugal and Belarus and among women in Portugal, and was substantial among men and
36
37 207 women in Norway (Figures 3, 4). While there was a general increase in PGLE due to obesity,
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39 208 this trend stagnated among women in CEE from around 1990 onwards, and levelled off after
40
41 209 1995 among women in Denmark and Switzerland.
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47 210 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
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49 211 **26 European countries and the USA between 1975-2012, in men**

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51 212 <approximately here>
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56 214 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
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58 215 **26 European countries and the USA between 1975-2012, in women**

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60 216 <approximately here>

217 Table 1 shows the impact of obesity on time trends in life expectancy at birth (e_0).

218 Overall, the average increase in e_0 between 1975 and 2012 was 7.26 years for men and 6.28

219 years for women in the 26 European countries. Without obesity, the average increase in e_0

220 would have been 8.04 years for men and 6.58 years for women; or 0.78 and 0.30 years

221 higher, respectively. Among men, obesity had the greatest impact on e_0 trends in Lithuania

222 and the USA (more than one year), and the smallest impact in Iceland and Sweden (0.5

223 years). Among women, obesity had the greatest impact on e_0 trends in the USA and Ireland

224 (0.7 years) and the smallest impact in Estonia and the Czech Republic (less than 0.1 year).

225 **Table 1: Impact of obesity on trends in life expectancy at birth (e_0) in 26 European**

226 **countries and USA 1975-2012, by sex**

Country	Change in e_0 with obesity 2012-1975 (years)		Change in e_0 without obesity 2012-1975 (years)		Effect of obesity on e_0 change 2012-1975 (years)	
	Men	Women	Men	Women	Men	Women
	Austria	10.62	8.61	11.25	8.95	0.63
Belarus	-0.55	1.43	0.46	1.83	1.00	0.40
Belgium	8.85	7.63	9.46	7.99	0.61	0.36
Czech Republic	7.97	6.98	8.66	7.03	0.69	0.05
Denmark	6.78	5.03	7.40	5.36	0.63	0.33
Estonia	6.43	6.42	7.26	6.46	0.82	0.04
France	9.49	7.99	10.17	8.30	0.68	0.31
Finland	10.07	7.26	10.82	7.75	0.74	0.50
Hungary	5.29	6.18	6.17	6.36	0.87	0.18
Iceland	9.02	5.19	9.51	5.51	0.48	0.32
Ireland	9.40	8.40	10.22	9.10	0.83	0.69
Italy	10.19	8.56	10.81	8.89	0.62	0.33
Latvia	4.91	4.53	5.82	4.70	0.90	0.18
Lithuania	2.01	3.80	3.14	4.06	1.13	0.26
Luxembourg	11.78	9.27	12.50	9.65	0.72	0.37
Netherlands	7.68	5.10	8.26	5.6	0.56	0.49
Norway	7.70	5.33	8.42	5.86	0.74	0.51
Poland	5.90	6.74	6.81	7.00	0.91	0.27
Portugal	12.14	10.87	12.91	11.26	0.77	0.40

3	Russian Federation	2.05	2.62	3.06	2.89	1.02	0.28
4	Slovakia	5.65	5.82	6.52	6.16	0.88	0.34
5	Spain	8.82	8.75	9.62	9.14	0.79	0.39
6	Sweden	7.69	5.59	8.18	5.93	0.49	0.33
7	Switzerland	8.98	6.63	9.55	6.93	0.58	0.30
8	Ukraine	0.48	1.73	1.26	1.94	0.78	0.21
9	United Kingdom	9.46	6.96	10.20	7.55	0.74	0.59
10	USA	7.86	4.89	8.90	5.61	1.04	0.71
11	Average CEE countries	4.01	4.63	4.92	4.84	0.90	0.22
12	Average Western countries	9.10	7.09	9.76	7.50	0.66	0.41

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228

229 Discussion

230 Summary of results

231 In the 26 European countries studied, the share of mortality due to obesity in 2012 was, on
 232 average, 11% among men and 10% among women. PGLE due to obesity in 2012 ranged from
 233 0.86 to 1.73 years among men, and from 0.66 to 1.54 years among women. Overall, PGLE
 234 increased between 1975 and 2012, albeit more quickly among men (average annual
 235 increase: 2.68%) than among women (1.33%). Among women in Denmark, Switzerland, and
 236 the CEE countries the increase in PGLE levelled off after 1995. Without obesity, the average
 237 increase in e_0 between 1975 and 2012 would have been 0.78 years higher among men and
 238 0.30 years higher among women.

239 Evaluation of data and methods

240 Using the recent advances in obesity data, it is now possible to study the impact of obesity
 241 on life expectancy for a large number of countries and a long period of time. Two
 242 methodological issues warrant our attention, however.

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3 243 First, in calculating the share of mortality due to obesity (OAMF), which also forms
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5 244 the basis for our PGLC calculations, we were hindered by limitations in the available
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8 245 prevalence and RRs data, which also affected the method used. As has previously been
9
10 246 documented, OAMF estimates are sensitive to the data and the methods used (27).

11
12
13 247 In selecting obesity prevalence data, we used the longest validated time series based
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15 248 on population-based measurement studies that are suitable for studying the impact of
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17
18 249 obesity on long-term life expectancy trends across Europe (13). For those countries with less
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20 250 available obesity data – especially the CEE countries a portion of the data we used were
21
22 251 merely the result of modelling. Thus, the resulting estimates should be treated with some
23
24
25 252 caution . By contrast, for the non-CEE countries, most of the data we used pertain to
26
27
28 253 measured data (13). Supplementary Material, Table S3 gives the confidence intervals around
29
30 254 the age-standardised prevalence estimates for each country by sex in order, as to provide
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32 255 more information on the relative reliability of the data for the different countries in our
33
34
35 256 analysis.

36
37 257 Because age- and sex-specific RRs of mortality associated with obesity are not readily
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39 258 available by country and year, we have decided to apply to all of the countries studied age-
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42 259 and sex-specific RRs from Western European and US populations that are largely suitable for
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45 260 our setting, as had previously been done (10). Although RRs could differ slightly across
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47 261 contexts, studies that compared RRs across continents found only small differences in RRs
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50 262 between Europe and North America (7). Consequently, we do not expect to observe large
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52 263 differences between individual countries. In addition, as time-variant European RRs were
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54 264 not available, we had to apply time-constant RRs, even though it is possible that changes in
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57 265 the association of obesity with mortality – which could, for example, occur because of
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59 266 improvements in the treatment of chronic diseases – have affected the impact of obesity on
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3 267 life expectancy. Previous studies that assessed changes over time in the association of
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5 268 obesity with mortality did so only for the US, and, unfortunately, provided mixed evidence,
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8 269 with some of these studies reporting a decline (18, 28, 29), and others finding an increase
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10 270 (30). Therefore, before implementing time-variant European RRs, more information on their
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13 271 direction is required. Similarly, comparable country-specific RRs are urgently needed. In
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15 272 addition, the choice of these RRs along with their reference group might exert an effect in
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18 273 our estimates. Based on the available data, only a fairly simple – albeit common applied –
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20 274 the weighted sum method could be applied (27) to estimate the OAMFs. The application of a
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23 275 more advanced methodology (27) could have affected the OAMFs and thus the PGLE levels,
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25 276 but less the trends(31). The lack of information on the uncertainty of the RRs we used
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28 277 limited us in estimating confidence intervals for the OAMFs and PGLEs.

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30 278 Second, besides being the result of the OAMFs, the PGLE estimates can also be
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32 279 affected by all-cause mortality levels and trends as age- and sex-specific all-cause mortality
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35 280 rates are used to estimate PGLE. Since all-cause mortality fluctuated greatly in CEE in the
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37 281 analysed period (12), short-term variations in PGLE in CEE countries should be treated with
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40 282 more caution.

41 42 283 **Explanation of results**

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45 284 In 2012, the PGLE due to obesity were, on average, 1.22 years for men and 0.98
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48 285 years for women in the 26 European countries, and 1.73 years for men and 1.43 years for
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50 286 women in the USA. A comparison of our 2006 e50 estimates with those of Preston et al. (10)
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53 287 for the same countries uncovered only small differences, except among men in the USA (our
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55 288 estimate was 0.56 years lower) and women in the UK (our estimate was 0.29 years lower)
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58 289 (see Supplementary Material, Table S4). Given that approximately the same methodology
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60 290 was used to estimate the OAMFs, the observed differences are most likely due to the use of

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3 291 different obesity prevalence and RRs data. Preston used prevalence data from national
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5 292 representative surveys and RRs from the Prospective Studies collaboration (10). Given that
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8 293 the observed differences do not have the same direction for the different countries, we
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10 294 believe that these differences are mainly attributable to the prevalence data used. To
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13 295 further evaluate our observed PGLE levels, we compared them with own PGLE estimates for
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15 296 smoking and alcohol (32). Our PGLE estimates for smoking were 2.38 years for men and 1.00
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18 297 year for women in Western Europe, and 3.82 years for men and 0.67 years for women in
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20 298 CEE. Our PGLE estimates for alcohol were 0.90 years for men and 0.44 years for women in
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23 299 Western Europe, and 2.15 years for men and 1.00 year for women in CEE (32) while our
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25 300 average PGLE for obesity was 1.08 among men and 0.86 among women in Western Europe,
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28 301 and 1.44 among men and 1.16 among women in CEE. Thus, obesity's impact on life
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30 302 expectancy lies between that of smoking and alcohol, and can be considered significant.

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33 303 In our study, we found that PGLE due to obesity was increasing, but that this trend
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36 304 differed across countries and between the sexes. This overall trend can be explained by the
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38 305 general increase in obesity prevalence in European countries (see Supplementary Material,
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40 306 Figure S3) (13) and the resulting growth in the burden of obesity (3), which is also reflected
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43 307 in the OAMFs (Figure 1, Figure S1) in these countries.

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46 308 At the same time, parts of the observed variation in the increase in PGLE estimates
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49 309 across the USA, Western Europe, and CEE and between the sexes reflect differences in the
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51 310 onset, the development, and the impact of the obesity epidemic in these countries and in
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54 311 men and women. Across the countries studied, the absolute increase in PGLE was largest
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56 312 among women and second-largest among men in the USA. This pattern is in line with
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58 313 evidence showing that between 1980 and 2008, obesity increased much more in the USA
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3 314 than in Europe(1, 33). This rapid progression of the obesity epidemic in the USA and its large
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5 315 impact on life expectancy has been attributed to an increasingly obesogenic environment
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8 316 caused by factors such as changes in food preparation and processes that promote the
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10 317 consumption of calorically dense foods, and a pronounced decrease in physical activity levels
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13 318 (34). The obesity epidemic has progressed more slowly in Western Europe than in the USA(1,
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15 319 13). However, obesity levels in countries like the UK and Ireland are rapidly approaching
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18 320 those in the USA (35), as our PGLLE estimates also show.

21 321 In the CEE countries, the PGLLE trends track the evolution of the obesity epidemic in
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23 322 that region (see Supplementary Material, Figure S3). Obesity levels have been higher in CEE
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26 323 than in Western Europe since 1980 (36, 37), which suggests that the epidemic started earlier
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28 324 in CEE. As a result of this earlier onset, the impact of obesity (as expressed in terms of OAMF
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31 325 and PGLLE) in the 1970s and 1980s was at times even greater in CEE than in the USA,
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33 326 especially among women. While there are many potential explanations for this early onset
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36 327 of the obesity epidemic in CEE, the available data indicate that the main factors were the
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38 328 relatively high total energy supply and energy intake in CEE in those years (38).

41 329 The overall progress of the obesity epidemic was lower in CEE than in Western
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43 330 Europe, and the increase was not constant (1). Indeed, in CEE, increases in obesity
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46 331 prevalence(1, 39), OAMFs, and PGLLE stagnated in the 1980-2008 period, and were more
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49 332 pronounced in the 1990s (1, 39). However, as these countries started the study period with
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51 333 higher obesity prevalence levels, these trends resulted in the CEE having higher average
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54 334 PGLLE levels than the West. The pattern of stagnation observed in the CEE, could be
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56 335 explained by the decrease in energy supplies at the beginning of the 1990s in CEE (37)
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58 336 resulting from the dramatic economic and political changes in those countries (3, 36, 39) and
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3 337 which in turn affected the socio-economic status of the population (SES). Among CEE
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6 338 women, the increase in obesity starting in the 1990s was smaller than it was in the previous
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8 339 period, and was smaller than it was among CEE men. The lower risk of obesity observed
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10 340 among women than among men with low socioeconomic status (SES) in low-income
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13 341 countries (40) may explain this difference.
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16 342 In Western Europe, a stagnation in PGLLE levels was observed among women in
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18 343 Denmark and Switzerland after 1995. This finding seems to be in line with studies reporting a
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20 344 levelling-off of mean BMI since the 1990s (41); and in specific sub-populations, such as
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22 345 adults with high SES in regions within Switzerland, Italy, France, and Finland
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24 346 (37). Although dietary and physical activity information is spreading equally across
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26 347 socioeconomic groups, those with higher SES have a greater ability and capacity to adopt a
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28 348 healthier dietary and physical activity pattern (42). In addition, it appears that higher SES
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30 349 women in particular are more health-conscious, have healthier food habits, and are more
31
32 350 prone to follow nutritional recommendations (43) as they are under greater social pressure
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34 351 to be thin (44). Similarly, countries with higher income levels and lower levels of inequality
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36 352 (45), like Switzerland and Denmark, tend to have lower obesity levels, especially among
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38 353 women.
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46 354 When we considered the impact of obesity on life expectancy in the 26 European
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48 355 countries, we found that without obesity, the increase in e0 between 1975 and 2012 would
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50 356 have been, on average, 0.78 years higher among men and 0.30 years higher among women.
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52 357 These figures account for approximately 10% of the average change in e0 between 1975 and
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54 358 2012 among men, and 5% among women. It is therefore clear that the impact of obesity on
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56 359 changes in e0 should not be ignored. Moreover, the impact of obesity on life expectancy
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3 360 levels and on life expectancy trends is likely to increase, as previous studies have also
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5 361 suggested (8). There are several indicators pointing in that direction, including evidence that
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8 362 obesity's impact is already substantially greater in the USA (13% among men and 15%
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10 363 among women) than elsewhere; obesity prevalence is increasing rapidly in most European
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12 364 countries (see Supplementary Material, Figure S3); obesity is increasing in severity; and the
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15 365 duration of obesity is rising in younger generations (8).

366 **Conclusion and implications**

367 Obesity was proven to have an impact on both life expectancy levels and trends in
368 Europe. The observed differences in the increase in the impact of obesity across countries
369 and between the sexes reflect differences in the onset and the progression of the obesity
370 epidemic, and can be linked to contextual factors (economic conditions, obesogenic
371 environment, energy supplies), as well as to differences in people's ability and capacity to
372 adopt healthier lifestyles.

373 It is likely that in the future obesity will have a larger impact on mortality and life
374 expectancy in Europe, as obesity prevalence and obesity-attributable mortality continue to
375 increase in the majority of countries. These trends will have important health, economic,
376 and social implications. Specifically, the increasing prevalence of obesity among European
377 populations, and especially at younger ages, will lead to an increased prevalence of obesity-
378 related disorders, as well as to increases in the mortality burden associated with obesity and
379 in obesity's effects on life expectancy and quality of life. Thus, obesity will constitute an
380 additional burden for societies, economies, and public health. It is therefore crucial that
381 effective public health initiatives are undertaken to tackle the obesity epidemic and its
382 effects on public health. Such initiatives should address the multifactorial and complex

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3 383 obesity aetiology; the clear differences between countries and the sexes; as well as the
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5 384 factors underlying these differences, such as contextual factors and differences in
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8 385 individuals' ability and capacity to adopt healthier lifestyles.
9

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18 389 improved and robust mortality projections, grant no. 452-13-001; see
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20 390 www.futuremortality.com.
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26 27 28 392 **Conflict of Interest**

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30
31 393 None declared.
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36 37 38 395 **Author contribution**

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41
42 396 N.Vidra contributed to the conception and design of the work; to the acquisition, analysis,
43
44 397 and interpretation of data for the work; drafted and revised the work critically for important
45
46 398 intellectual content; approved the final version of the work to be published and agrees to be
47
48 399 accountable for all aspects of the work in ensuring that questions related to the accuracy or
49
50 400 integrity of any part of the work are appropriately investigated and resolved.
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55 401 S. Trias-Llimós contributed to the analysis, and interpretation of data for the work; revised it
56
57 402 critically for important intellectual content; approved the final version of the work to be
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3 403 published and agrees to be accountable for all aspects of the work in ensuring that questions
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5 404 related to the accuracy or integrity of any part of the work are appropriately investigated
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8 405 and resolved.
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11 406 F. Janssen contributed to the conception and design of the work; to the interpretation of
12
13 407 data for the work; revised the work critically for important intellectual content; approved
14
15 408 the final version of the work to be published and agrees to be accountable for all aspects of
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17 409 the work in ensuring that questions related to the accuracy or integrity of any part of the
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19 410 work are appropriately investigated and resolved.
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23 24 25 411 **Data statement**

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28 412 Obesity prevalence data can be obtained from NCD Risk Factor Collaboration (NCD-RisC)
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30 413 (www.ncdrisc.org).

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34 414 All-cause mortality and exposure population data can be obtained from the Human
35
36 415 Mortality Database (<http://www.mortality.org>).

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58 423 robust mortality projections, grant no. 452-13-001. See www.futuremortality.com

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433 [_BMI_statistics](http://ec.europa.eu/eurostat/statistics-explained/index.php/Overweight_and_obesity_-_BMI_statistics).

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3 544 **Figure legends**
4

5 545 **Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European**
6 **countries* (by 5 regions) and USA, 1975-2014, 18-100 years**
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11 548 * Countries within the same region are presented with the same colour

12
13 549 **Central Europe:** Czech Republic, Hungary, Poland, Slovakia

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15 550 **Eastern Europe:** Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

16
17 551 **Northern Europe:** Denmark, Finland, Iceland, Norway, Sweden

18
19 552 **Southern Europe:** Italy, Portugal, Spain

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21 553 **Western Europe:** Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland,
22 United Kingdom

23
24 555 **USA:** United States of America

25
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27
28 557 **Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality**
29 **was eliminated, in 26 European countries* (differentiating Western and Central Eastern**
30 **Europe) and the USA, 1975-2012, 18-100 years**
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36 561 * Countries within the same region are presented with the same colour

37
38 562 **Central Eastern Europe:** Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland,
39 Russian Federation, Slovakia, Ukraine

40
41 564 **Western Europe:** Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy,
42 Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

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44 565 **USA:** United States of America

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50 568 **Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in**
51 **26 European countries and the USA between 1975-2012, in men**
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57 571 **Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in**
58 **26 European countries and the USA between 1975-2012, in women**
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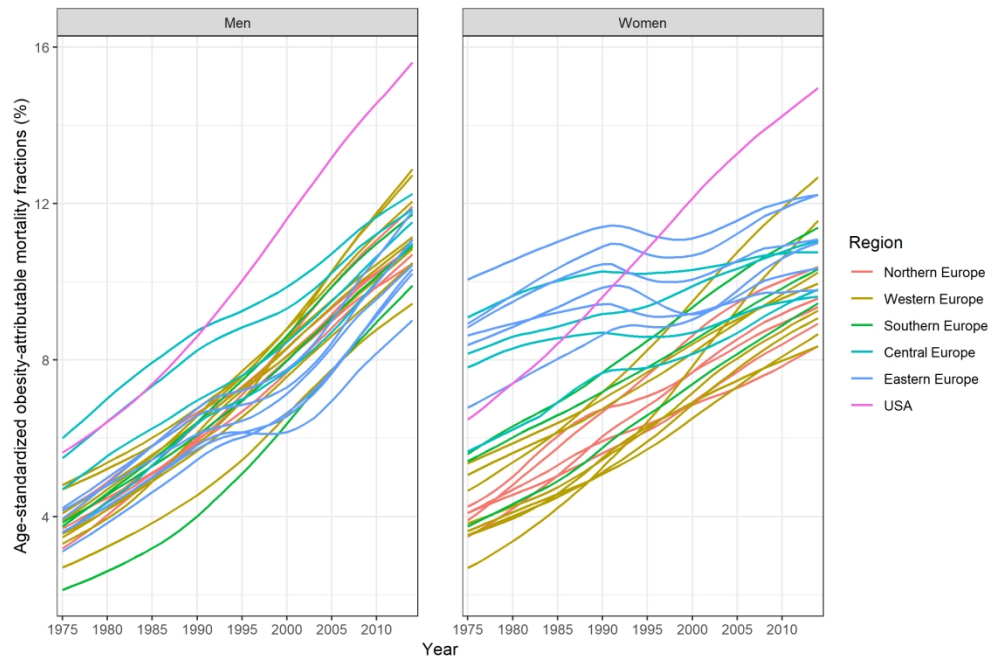


Figure 1: Age-standardised obesity-attributable mortality fractions in 26 European countries* (by 5 regions) and USA, 1975-2014, 18-100 years

* Countries within the same region are presented with the same colour

Central Europe: Czech Republic, Hungary, Poland, Slovakia

Eastern Europe: Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

Northern Europe: Denmark, Finland, Iceland, Norway, Sweden

Southern Europe: Italy, Portugal, Spain

Western Europe: Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom

USA: United States of America

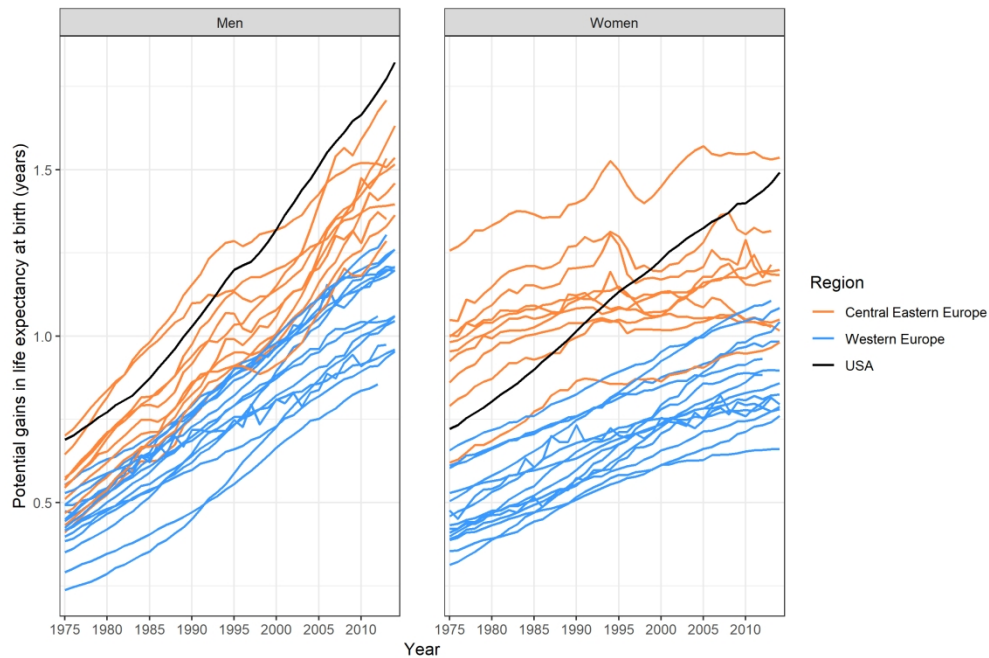


Figure 2: Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries* (differentiating Western and Central Eastern Europe) and the USA, 1975-2012

* Countries within the same region are presented with the same colour

Central Eastern Europe: Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Ukraine

Western Europe: Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

USA: United States of America

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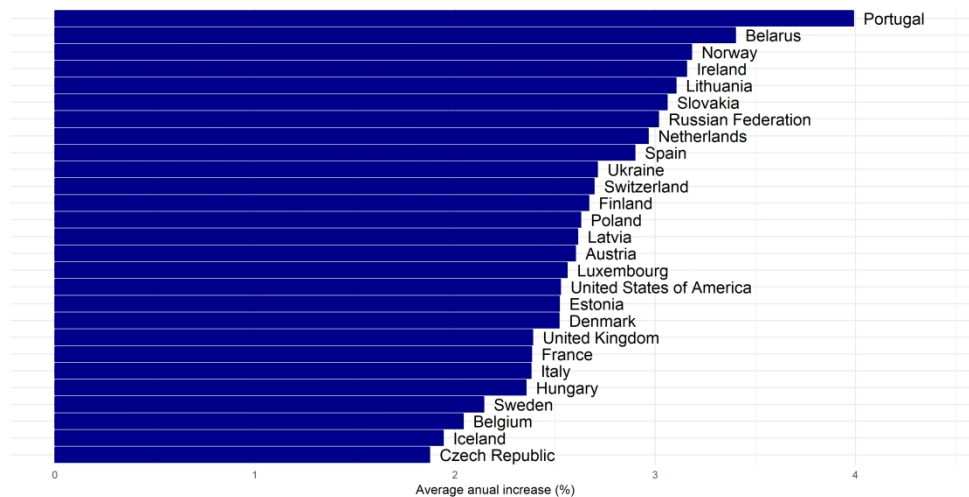


Figure 3: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in men

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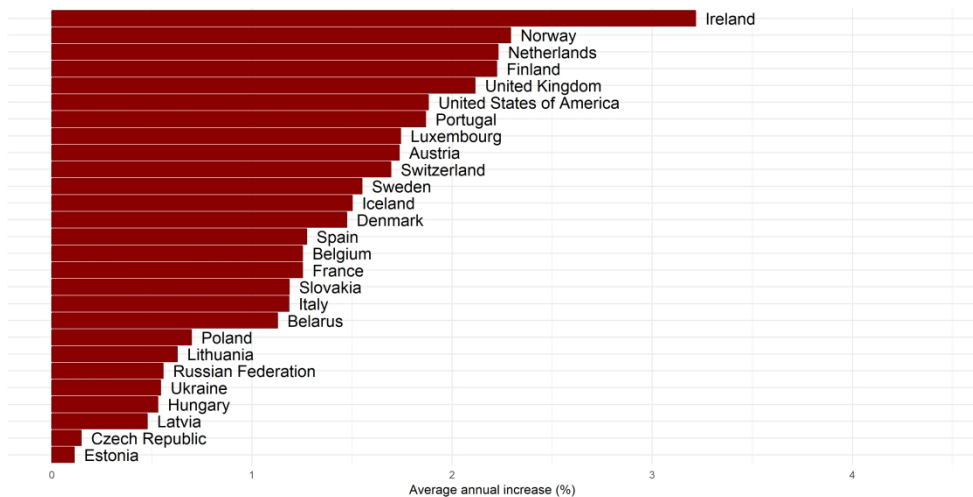


Figure 4: Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, in women

Impact of obesity on life expectancy among different European countries, 1975-2012

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Supplementary material

Table S1: Age-and sex-specific RRs of dying from obesity from the meta-review from Lobstein et al. (2010)

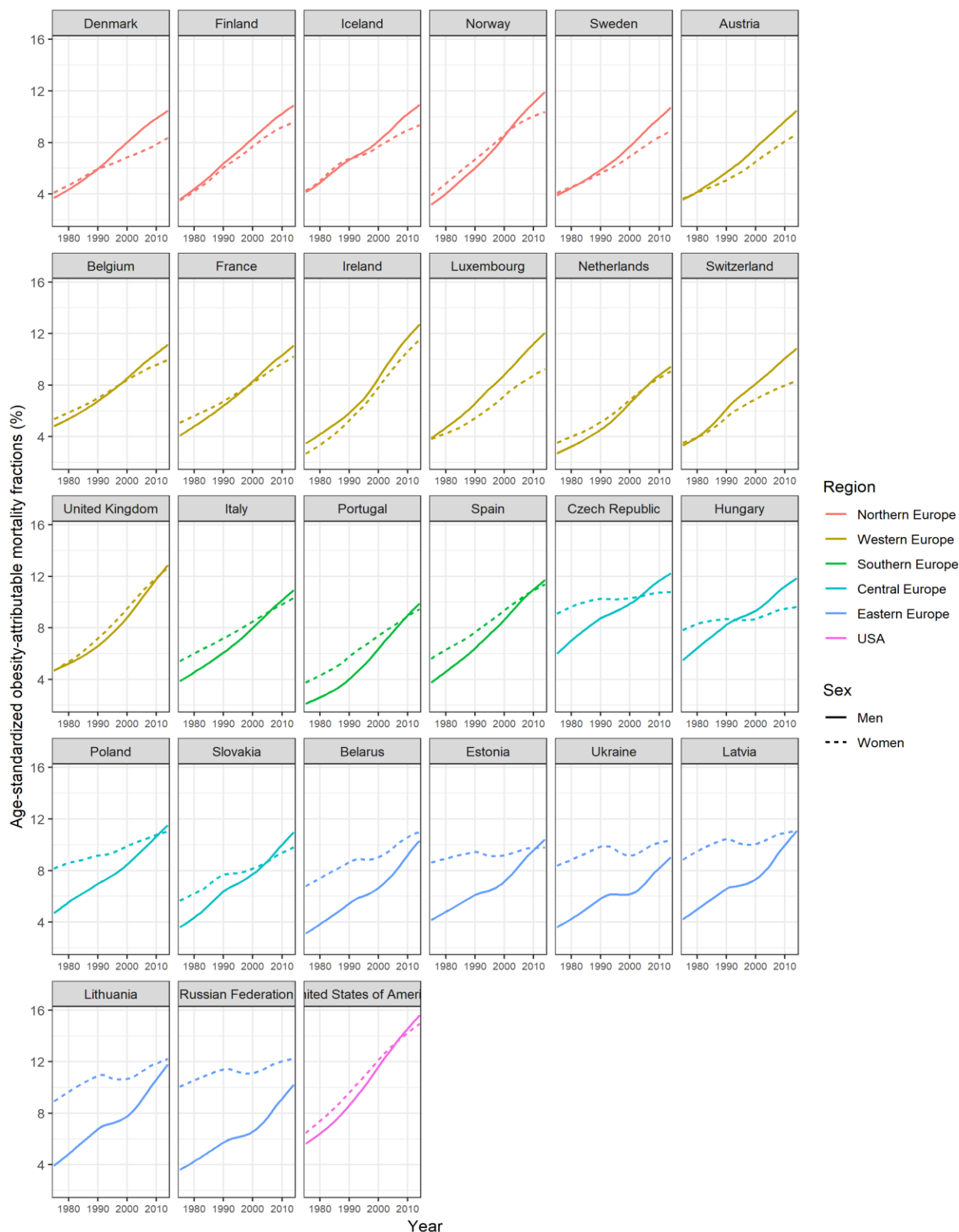
Age	RR*	
	Men	Women
<50	1.55	1.5
50-59	1.539	1.49
60-69	1.5225	1.475
70+	1.495	1.45

*Reference group for the RRs: normal weight ($18.5 \leq \text{BMI} \leq 24.9 \text{ kg/m}^2$)

Table S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, in 1975 and 2012, 18-100 years

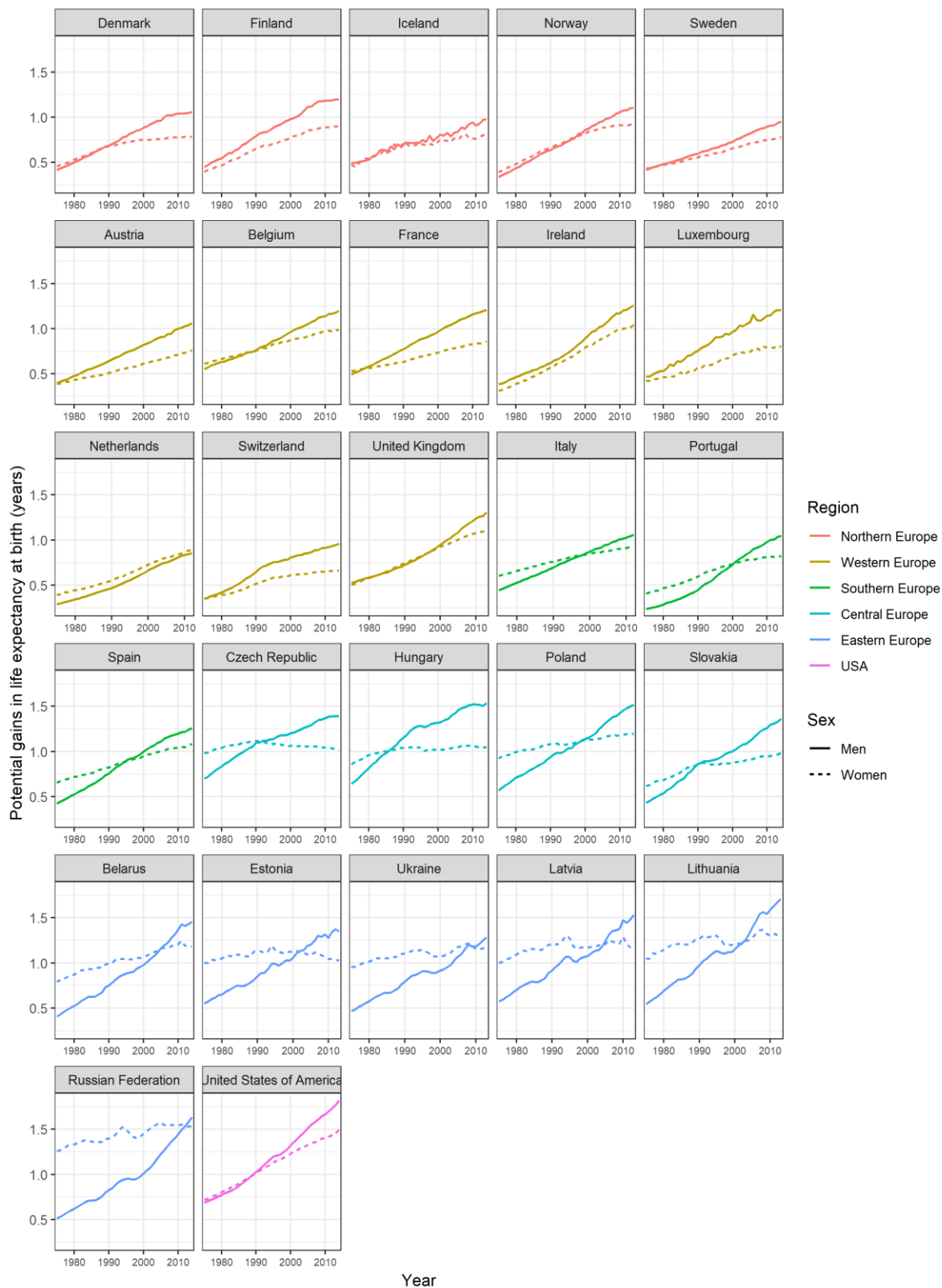
Country	PGL 1975		PGL 2012	
	Men	Women	Men	Women
Central Eastern Europe (CEE)				
Belarus	0.41	0.79	1.41	1.19
Czech Republic	0.70	0.98	1.39	1.03
Estonia	0.55	1.00	1.37	1.04
Hungary	0.64	0.86	1.52	1.04
Latvia	0.58	1.00	1.48	1.18
Lithuania	0.54	1.05	1.67	1.31
Poland	0.57	0.93	1.48	1.19
Russian Federation	0.51	1.26	1.53	1.54
Slovakia	0.43	0.62	1.31	0.96
Ukraine	0.47	0.95	1.25	1.16
Average CEE	0.54	0.94	1.44	1.16
Western Europe				
Austria	0.40	0.39	1.03	0.73
Belgium	0.55	0.61	1.17	0.97
Denmark	0.42	0.46	1.04	0.79
France	0.49	0.53	1.18	0.84
Finland	0.45	0.40	1.19	0.90
Ireland	0.38	0.31	1.21	1.01
Iceland	0.49	0.48	0.97	0.80
Italy	0.44	0.60	1.06	0.93
Luxembourg	0.47	0.42	1.19	0.79
Netherlands	0.29	0.39	0.86	0.88
Norway	0.34	0.39	1.07	0.91
Portugal	0.24	0.41	1.01	0.81
Spain	0.42	0.66	1.22	1.05
Sweden	0.42	0.43	0.91	0.76
Switzerland	0.35	0.35	0.93	0.66
United Kingdom	0.53	0.50	1.27	1.09
Average Western Europe	0.41	0.48	1.08	0.86
USA	0.69	0.72	1.73	1.44
Average European countries	0.46	0.64	1.22	0.98
Average all countries	0.47	0.64	1.23	1.00

Figure S1: Age-standardised obesity-attributable mortality fractions in 26 European countries*, grouped by 5 regions and USA, 1975-2014, 18-100 years



* Countries within the same region are presented with the same colour

Figure S2: Potential gains in life expectancy at birth (PGL) if obesity-attributable mortality was eliminated, in 26 European countries*, grouped by 5 regions and USA, 1975-2012, 18-100 years



* Countries within the same region are presented with the same colour

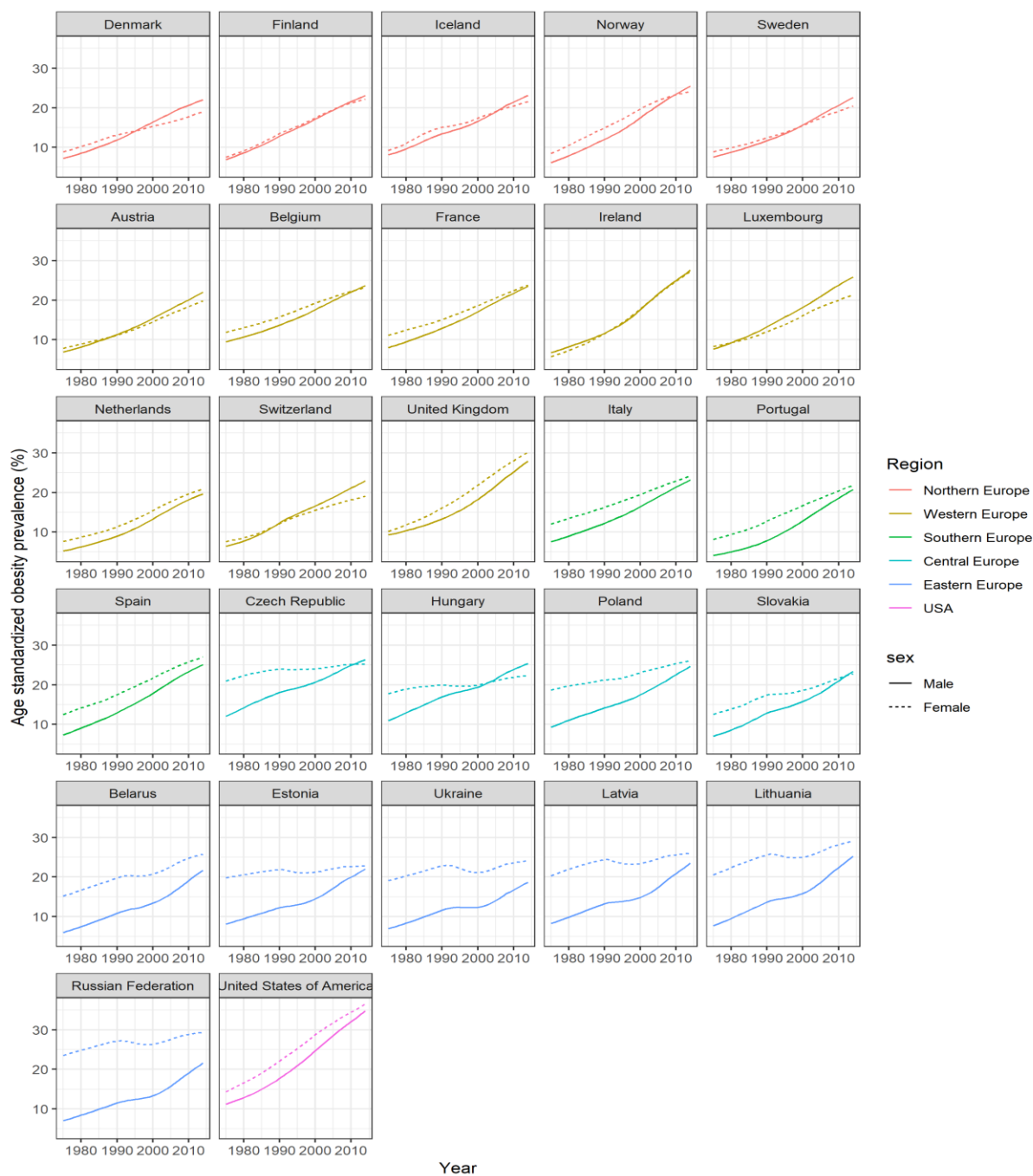
Table S3: Age-standardised obesity prevalence and 95% confidence intervals, in 26 European countries (differentiating Western and Central Eastern Europe) and USA, 18-100 years in 2012.

Country	Age-standardised (stand.) obesity prevalence (%)			
	Age-stand.	95% confidence intervals	Age-stand.	95% confidence intervals
	Men		Women	
Central Eastern Europe				
Belarus	20.4	13.6; 28.5	25.4	17.7; 34.1
Czech Republic	25.6	18.9; 33.4	25.2	18.3; 33.0
Estonia	21.0	16.0; 26.8	22.7	17.4; 28.8
Hungary	24.6	17.9; 32.0	22.1	15.4; 29.8
Latvia	22.2	15.2; 30.2	25.8	18.4; 34.5
Lithuania	23.8	16.9; 31.8	28.7	21.2; 37.1
Poland	23.6	18.0; 29.7	25.7	19.5; 32.5
Russian Federation	20.4	14.8; 26.8	29.1	22.6; 36.2
Slovakia	22.2	15.7; 29.6	22.2	15.8; 29.6
Ukraine	17.7	11.2; 25.7	23.9	16.3; 32.5
Western Europe				
Austria	21.1	14.7; 28.2	19.1	13.4; 25.5
Belgium	22.9	17.3; 29.1	22.7	17.1; 28.9
Denmark	21.3	15.5; 27.9	18.4	13.1; 24.5
France	22.6	16.3; 29.6	23.1	16.9; 29.9
Finland	22.3	17.1; 28.2	21.7	16.7; 27.3
Ireland	26.2	19.4; 33.8	26.0	19.5; 33.2
Iceland	22.3	15.6; 29.8	21.0	14.7; 28.3
Italy	22.3	17.0; 28.1	23.5	18.1; 29.6
Luxembourg	24.9	17.6; 32.9	20.7	14.3; 28.0
Netherlands	18.9	13.8; 24.5	20.3	15.3; 25.8
Norway	24.5	18.5; 31.2	23.7	18.0; 30.2
Portugal	19.6	13.8; 26.4	21.1	15.0; 28.1
Spain	24.2	18.5; 30.5	26.4	20.3; 32.8
Sweden	21.6	16.3; 27.4	19.8	14.7; 25.6
Switzerland	22.0	16.3; 28.3	18.6	13.1; 24.8
United Kingdom	26.5	22.3; 31.2	29.1	24.8; 33.6
USA	33.4	27.5; 39.5	35.5	29.7; 41.5

Table S4: Potential gains in life expectancy at age 50 (PGL e50) if obesity-attributable mortality was eliminated, own estimates and those by Preston et al.2011, in the same countries studied, in 2006

Country	PGL e50 2006, own estimates	PGL e50 2006, Preston's estimates	Difference
Men			
Austria	0.81	1.00	-0.19
Belgium	0.95	0.98	-0.03
Czech Republic	1.14	1.34	-0.20
Denmark	0.88	0.82	0.06
France	0.94	0.99	-0.05
Italy	0.88	0.90	-0.02
Netherlands	0.69	0.73	-0.04
Poland	1.14	1.37	-0.23
Spain	1.02	1.15	-0.13
Sweden	0.75	0.72	0.03
Switzerland	0.77	0.79	-0.02
United Kingdom	0.99	1.34	-0.35
USA	1.29	1.85	-0.56
Women			
Austria	0.62	0.71	-0.09
Belgium	0.86	0.73	0.13
Czech Republic	0.87	1.01	-0.14
Denmark	0.71	0.62	0.09
France	0.72	0.52	0.2
Italy	0.84	0.57	0.27
Netherlands	0.76	0.69	0.07
Poland	1.08	1.19	-0.11
Spain	0.95	0.87	0.08
Sweden	0.67	0.63	0.04
Switzerland	0.59	0.50	0.09
United Kingdom	0.94	1.23	-0.29
USA	1.18	1.28	-0.10

Figure S3: Age-standardised obesity prevalence in 26 European countries*, grouped by 5 regions and USA, 1975-2012, 18-100 years



* Countries within the same region are presented with the same colour