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PAPER

Body weight and the shape of the natural distribution of weight, in very large samples of German, Austrian and Norwegian conscripts

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OBJECTIVE: To investigate the shape of the natural distribution of body weight in conscripts.
DESIGN: Investigation of weight and weight distributions in German, Austrian and Norwegian conscripts.
SUBJECTS: A total of 10 706 651 West German conscripts (30 birth cohorts born between 1938 and 1971, except for the cohorts born 1941–1944), 507 095 Austrian conscripts (10 birth cohorts born between 1966 and 1975), and 27 311 Norwegian conscripts (1997 conscription).
RESULTS: In Germans, average body weight increased by 100 g/y up to birth cohort 1965, thereafter by 400 g/y, and by 200 g/y in Austrians. Body weight is not normally distributed, but skewed to the right. Also power transformation was inadequate to sufficiently describe the shape of this distribution. The right tail of weight distributions declines exponentially, beyond a cut-off of +0.5 standard deviations. There is a strong relation between average weight and the prevalence of obesity, except for those cohorts that suffered from severe starvation (1945–1948) during early and mid-childhood. These cohorts appeared to be more resistant against obesity.
CONCLUSION: Obesity appears to be a characteristic feature of a population as a whole, and does not seem to be a separate problem of only the obese people. It may be questioned whether (in terms of public health) the optimal solution for treating obesity is treating the obese people, or whether one should consider measures to reduce average weight in a population instead, as this might reduce the number obese people and the severity of the illness.
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Introduction

Obesity is a clinical and psychological problem of increasing prevalence worldwide.[1] It is associated with various risk factors for later disease and chronic illness,[2] and is ideally measured from body fat. Under screening conditions, body fat is usually estimated by skinfold thicknesses, and although less sensitive than these,[3] body mass index (BMI) (weight/height^2) has widely been accepted for identifying obesity, with a cut-off point of 30 kg/m^2 that is recognised internationally as a definition of adult obesity.[4] The increasing prevalence of obesity is also apparent in conscripts. After many decades of rapid increment, body stature has now stabilised close to 180 cm in German conscripts,[5] but body weight is still increasing. The present study illustrates this trend, and particularly focuses on heavy individuals, in very large cohorts of conscripts in three modern societies.

Material and methods

We investigated data on body weight of 10 706 651 West German conscripts, obtained from 30 annual cohorts (all birth cohorts born between 1938 and 1971, except for the cohorts born 1941–1944), given to us by the Institut für Wehrmedizinalstatistik und Berichtswesen, Remagen, of

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507 095 Austrian conscripts (all birth cohorts born between 1966 and 1975), and of 27 311 Norwegian conscripts (conscripted and investigated in 1997), given to us by the Seksjon for Helsestatistik, Statistik Sentralbyra, Oslo, Norway. The subjects were listed in tables consisting of 1 kg weight classes. Since conscription is compulsory in these three countries, the annual samples are assumed to comprise more than 95% of all men aged between 19 and 20 y.

Since weight does not follow a normal distribution, transformations of the raw data were evaluated which leads to a better approximation to the normal distribution. The family of power transformation $z = \text{sign}(\alpha)x^{\alpha}$ (in this case $-1 \leq \alpha < 0$ and $0 < \alpha \leq 1$ and $y = \log(x)$, if $\alpha = 0$) has often been effective and comprises a variety of popular transformation.[6] We used the coefficients $\alpha = 1$, 0.5, 0, -0.5, -1, and transformed the x-axis (body weight) of the weight tables according to:

$$\begin{array}{lll} \alpha = 1 & z = x^1 & z = x \\ \alpha = 0.5 & z = x^{0.5} & z = \sqrt{x} \\ \alpha = 0 & & z = \log(x) \\ \alpha = -0.5 & z = x^{-0.5} & z = -1/\sqrt{x} \\ \alpha = -1 & z = x^{-1} & z = -1/x \end{array}$$

When moving downwards from $\alpha = 1$, to $\alpha = -1$, more and more skewness to the right is eliminated. We calculated means and standard deviations of the five transformed weight distributions; we determined expected numbers of conscripts per 1 kg class according to each transformation, and compared the expected numbers with the observed numbers of conscripts of the natural weight distribution (Figure 2).

The right tail of natural weight distribution, ie the heavy individuals, declines in an almost ideal exponential manner. Thus, we also used a logarithmic transformation for the y-axis, and log 10-transformed the number of individuals per 1 kg class. By inspection, the cut-off at +0.5 standard deviations appeared to be the smallest s.d. above which the right tail of the distribution started to decline exponentially, ie when plotting numbers of conscripts per 1 kg class on semi-log paper, the result will always be a steadily declining linear line. We further investigated this behaviour and fitted the linear function ($y = a + bx$) through the semi-log transformed right tails (above +0.5 s.d.) of the weight distributions, and determined slope (b) and intercept (a). The slope (b) estimates log 10-numbers of heavy conscripts, and thus estimates the prevalence of overweight. The steeper the slope (b), the less frequent we find overweight and severely overweight individuals in the cohorts.

The smaller the number of individuals per class, the larger the sampling error. Initially, we corrected for the greater sampling error among the most heavy individuals, but since the results appeared quite independent from such correction, we later ignored the sampling error for the sake of simplicity.

Results

Average body weight of conscripts increased by 100 g/y in Germans, up to birth cohort 1965, and thereafter by 400 g/y, the average weight of Austrians increased by 200 g/y (Figure 1a). Body weight is not normally distributed (Kolmogoroff–Smirnoff test <0.001), but skewed to the right. Figure 1b illustrates the weight distribution of six annual cohorts (Germans, born 1940, 1950, 1960, 1970, Austrians, born 1970, and Norwegians, born 1977). Figure 1c shows the same distributions plotted on semi-log y-scale, and illustrates the almost perfect linear decline of log 10-transformed numbers of heavy individuals. This was found in all cohorts investigated (data not shown in detail). Due to digit preference, ie inaccurate weighing or recording, round weight classes (60, 65, 70, 75 kg etc) are over-represented in some cohorts (eg the 1940 German, and the Norwegian cohort, see also Figure 2). The German 1940 born cohort is printed in bold to

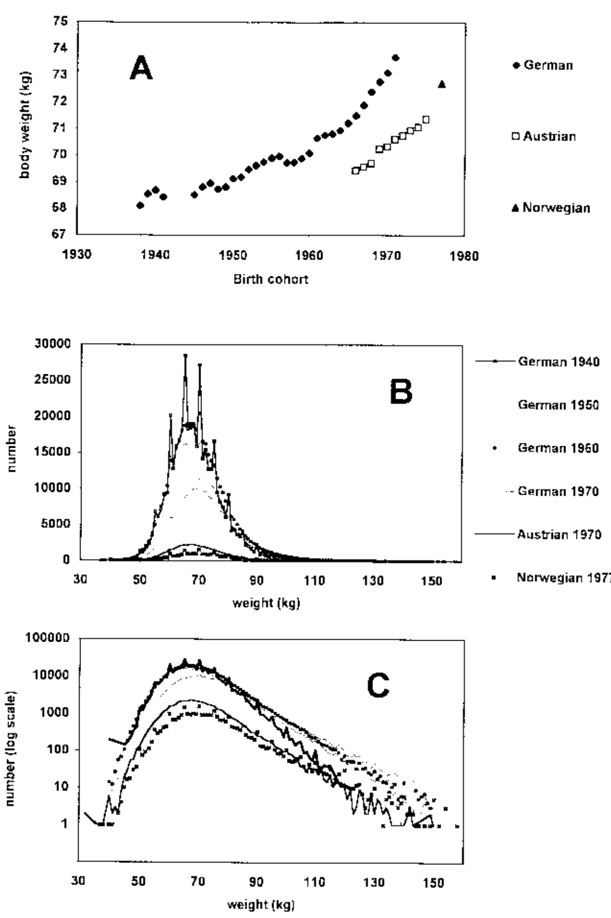

Figure 1 (a) Average weight of 30 German, 10 Austrian, and one Norwegian annual sample of conscripts. (b) Weight distribution of six complete annual conscript cohorts (German conscripts, born 1940, 1950, 1960 and 1970, Austrian conscripts, born 1970, and Norwegian conscripts, born 1977). (c) Weight distribution (b) on semi-log transformed y-axis.

underline that the slope of the right tail is steeper than in the later born cohorts.

Figure 2 exemplifies the effect of normalising power transformation using the 1938 born German cohort. Figure 2a shows the observed numbers per kg-weight class, and the estimated numbers according to power transformation with $\alpha = 1, 0.5, 0, -0.5, 0, -1$. Figure 2b shows the same distributions plotted on semi-log transformed *y*-axis. None of the five transformations truly satisfied. Whereas power transformation adequately depicts the exponential decline of the right tail of the weight distribution, when choosing the coefficients $\alpha = -0.5$, and $\alpha = -1$, the transformation certainly distorts the centre section of the distribution regardless of the α chosen. The residuals indicate (Figure 2c) that power transformation tends to overestimate conscript numbers just above average weight. The figure also illustrates the effect of digit preference. Very similar results were obtained in the other cohorts (data not shown).

The number of heavy individuals declines exponentially with increasing kg-weight class (Figure 1c). Yet the slope of this decline varied among the annual cohorts. The German 1940 cohort was not the only cohort with fewer heavy and very heavy individuals. The slope (*b*) depends on the year of birth (Figure 3a). In particular, those Germans who were born immediately before and just after World War II, and had suffered from the severe famine of 1945–1948 (rectangle in Figure 3a) during childhood (though not during infancy), had the smallest numbers of obese and severely obese individuals, with the lowest slopes (*b*), in particular the 1946-born cohort. Those who had suffered from starvation only during early infancy (born after 1946) or were born later, closely fitted into the trend of the subsequent years.

We then compared the historic changes of the slope (*b*) (Figure 3a) with the changes of average weight (Figure 1a). At first glance, both figures seem to closely resemble each other, and it appears that the prevalence of obesity is reflected by average body weight. However, when relating slope and average weight (Figure 3b), it becomes obvious that this is

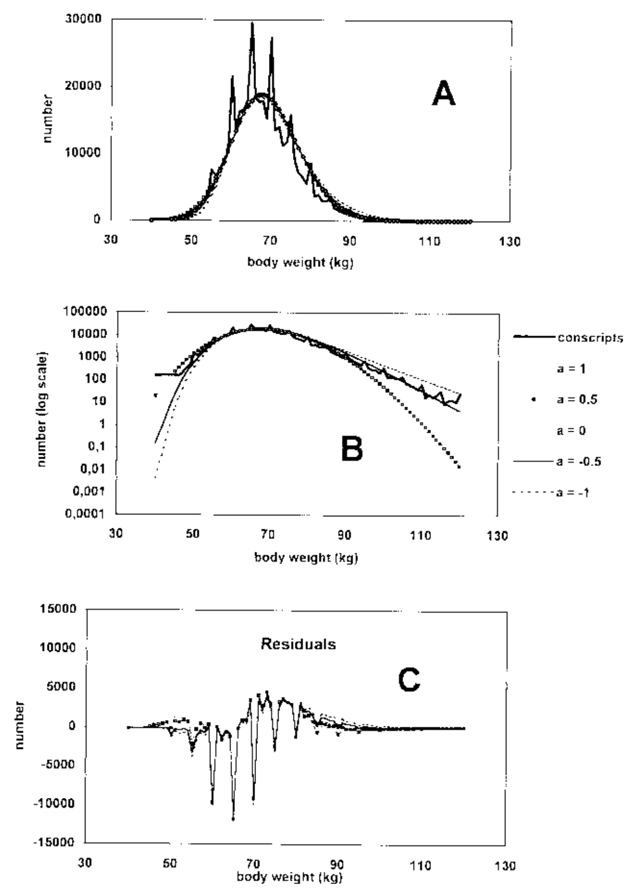

Figure 2 (a) Weight distribution of German conscripts born 1938, and estimates of conscript numbers after power transformation using the coefficients $\alpha = 1, 0.5, 0, -0.5, -1$. (b) Weight distribution and estimated distribution after power transformation (equivalent to (a) but on semi-log transformed *y*-axis). (c) Residuals (difference expected minus observed) after power transformation using the coefficients $\alpha = 1, 0.5, 0, -0.5, -1$.

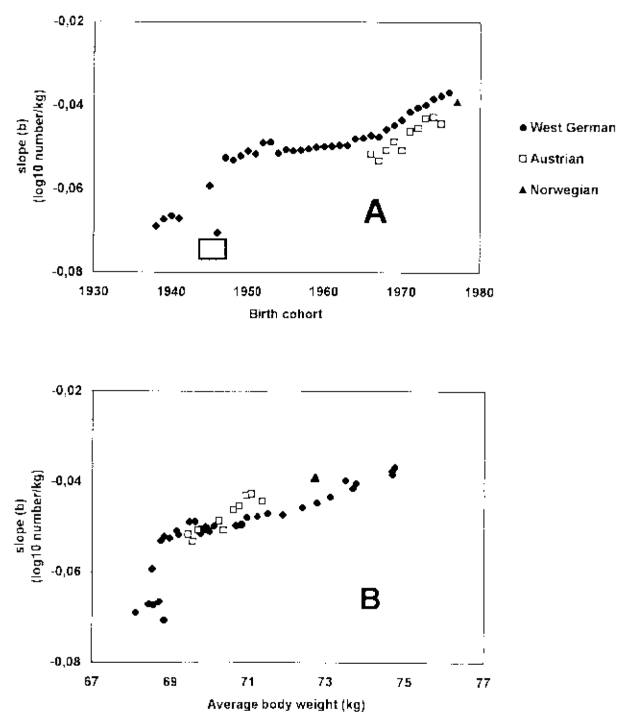

Figure 3 (a) The slope (*b*) of the right tail of German, Austrian and Norwegian conscripts (log10-transformed numbers of heavy individuals) related to year of birth (open rectangle refers to the period of starvation after World War II). (b) The slope (*b*) of the right tail of German, Austrian and Norwegian conscripts related to average body weight. Birth cohorts born before 1947 showed lower slopes, indicating reduced prevalence of overweight in individuals that experienced severe starvation during early and mid-childhood.

only partially true. Only in birth cohorts born after 1946 do the slope (*b*) and average weight closely correlate regardless of whether the samples were taken from Germany, Austria or Norway. However this was different in those six German cohorts that had undergone starvation during childhood as they were born in 1946 or before. Although average adult weight of these cohorts did not particularly differ from that of later born cohorts, the cohorts contained significantly less heavy and very heavy individuals, ie showed significantly ($P < 0.001$) reduced prevalence of overweight and obesity.

Discussion

The increasing prevalence of obesity and its importance in the Western World has been described thoroughly.[1] The present study exemplifies this trend in recent history in very large cohorts of conscripts of three modern societies, and investigates the natural distribution of weight. Body weight is not normally distributed. Also power transformation fails to adequately normalise the body weight distributions, and tends to overestimate conscript numbers just above average weight. Beyond a cut-off at +0.5 s.d. the right tail of weight distributions declines exponentially. This has certain practical implications as it facilitates estimating the prevalence of very obese people just by plotting observed numbers on semi-log paper, and extrapolating the linear trend.

Conscript data are difficult to interpret since measurements are usually not obtained by skilled personnel, and thus prone to measurement inaccuracy. Yet, the present analysis is based on data from more than 11 million people, and the figures indicate that the artefacts, although obvious, appear limited to digit preference, ie inaccurate weighing or recording or round weight classes (60, 65, 70, 75 kg etc). We have no evidence that our results, in particular the investigation of the exponential characteristic of the right tail of the distributions, may be flawed by poor quality of the data.

Body weight distributions are commonly analysed by power transforming[6] the *x*-axis (kg-weight class), to remove, or at least reduce, curvature and heteroscedasticity.[7–9] Yet, this technique appeared unsatisfying in the present analysis. Since we did not intend to provide additional mathematical models for describing body weight distributions, but for clinical reasons rather focused on heavy individuals, we limited our attention to the right tail of the natural distribution, and refrained from further searches for improved models for describing weight distributions.

Since World War II, the average weight of conscripts has increased by up to 400 g/y in recent German cohorts, and also the prevalence and degree of obesity have increased. For the first time, however, it is shown that both parameters, average weight and the prevalence of obesity, are closely related. It is interesting to note that this relation is not a linear one, but it appears to be exponential. Only a few German cohorts, all of them born before 1947 and starved during early and mid-childhood, in particular the 1946-born cohort, behaved differently. Although average body weight of these cohorts did not differ significantly from that of later born ones, the number of obese and severely obese individuals was significantly lower. This might indicate that food intake in early childhood is an important risk factor for later overweight, and possibly that starvation, in particular, reduces the risk of obesity in later life.

According to our opinion, the strong linkage between average weight and overweight, suggests that obesity, in fact, is a characteristic feature of a population as a whole, and not a separate problem of only obese people. The fattest individuals in the population are getting (exponentially) fatter in line with the average individual.

It remains to be investigated whether these findings are limited to conscripts, or whether they are part of a more general biological phenomenon present in both sexes and other age groups. If so, it may be questioned whether (in terms of public health) the optimal solution for treating obesity, in fact, is treating the obese people, or whether one should consider measures to reduce average weight in a population, in order to reduce the number obese people and the severity of the illness, and to focus on early childhood nutrition and its impact on later weight gain.

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