Filling the weight gap: Estimating body weight and BMI using height, chest and upper arm circumference of Swiss conscripts in the first half of the 20th century

Fabienne P Trueb [1], Jonathan CK Wells [2], Frank J Rühli [3], Kaspar Staub [3,4] *, Joël Floris [3,5] *[§]

[1] Medical Faculty, University of Zurich, Switzerland
[2] Childhood Nutrition Research Centre, UCL Great Ormond Street Institute of Child Health, London, UK
[3] Institute of Evolutionary Medicine, University of Zurich, Switzerland
[4] Zurich Center for Integrative Human Physiology (ZIHP), University of Zurich, Switzerland
[5] Department of History, University of Zurich, Switzerland

* These authors contributed equally to this work: Last authorship

§ Corresponding author: Joël Floris, joel.floris@iem.uzh.ch

Abstract:

We estimate weight and BMI values based on height, chest circumference, and mid upper arm circumference measures of Swiss conscripts in the city of Zurich for each year between 1904 and 1932. Height, chest circumference, and mid upper arm circumference were measured each year from 1904 to 1951. Body weight is available from 1933 to 1951. We used prediction equations from the literature, and also developed our own equations, which we tested and validated on the dataset from 1933 to 1951. We used a representative sample of usually 19-year-old Swiss males (N = 88,792, coverage > 88%). There was an increase in average height and chest circumference between 1904 and 1951. During both world wars, chest circumference, mid upper arm circumference, weight, and BMI decreased, while height stagnated. Overall mean weight and BMI increased from 1904 to 1951, but decreased during the Great Depression. After World War II, weight quickly returned to the pre-war and pre-Great Depression level, while BMI had not reached the 1933 level by 1951. Average weights of the lower and middle socioeconomic groups were catching up with average weight of the upper socioeconomic group from 1904 to 1951. The convergence in height is less pronounced. Finally, we show that it is possible to accurately predict mean weight and BMI from other anthropometric measurements. We suggest that our estimation approach could be replicated for other historical populations to obtain more information on how nutritional status changed over time.

1. Introduction

Anthropometric measurements assess the size, proportions, and composition of the human body, and are common external indicators of nutritional status (Willett and Hu 2012; WHO Expert Committee 1995). Because nutritional status is an important part of human health, growth in children and body dimensions at all ages also reflect the overall health and welfare of individuals and populations (WHO Expert Committee 1995). Therefore anthropometric measurements are used to determine the inclusion of individuals, families, and communities in intervention programs to improve nutrition and health in general, as well as to evaluate those interventions (WHO Expert Committee 1995).

Changes in the size and shape of the human body can be linked to various environmental changes (Ruff 2018b; Floud et al. 2011). The reconstruction of body size and shape of past populations is a major focus in archaeological and anthropological research (Ruff 2018a; Steckel and Rose 2002). It is used to infer behaviour, based on long-bone structure, and to study the impact of changes in climate and nutrition on the human body. One main emphasis is to assess health status using variation in stature (Ruff 2018a). Changes in average height have also been widely used in anthropometric history as a marker of changes in living standards (Floud et al. 2011; Steckel 2009). In both Ruff and Floud et al., stature as well as weight and BMI are analysed (Ruff et al. 2018; Carson 2016; Floud et al. 2011; Ruff et al. 2005). While in archaeological and anthropological research, weight and BMI values have been estimated indirectly from skeletal remains, studies in anthropometric history have relied on historical sources to provide direct weight measurements.

In both cases, sample size has often been small, not least because direct weight measurements are scarce compared to height records. In addition, there is little information on weight and BMI values of a representative sample of young people who are generally healthy. To our knowledge, no studies have reconstructed and estimated body weights based on other available anthropometric measurements for a period of several years and for a representative historical population living in the first half of the 20th century. The existing studies in anthropometric history are either based on available weight measurements from the late 19th century, or on specific subpopulations like cadets, boarding school children or prisoners (Komlos and Carson 2017; Komlos and Brabec 2010).

Therefore, it is still largely unclear how BMI values developed in historical populations in the first half of the 20th century, which included boom times and economic crises, as well as two world wars (Komlos and Carson 2017). In Switzerland, there was an above average increase in GDP per capita since the end of the 19th century, making Switzerland one of the richest countries in the world by World War I (Floris, Höpflinger, et al. 2019). At the same time, Swiss on average became taller and experienced increased life expectancy, though in contrast to GDP per capita, they were not at the top of European rankings for height or life expectancy at birth (Floris, Höpflinger, et al. 2019). The same is true for real wages. The increase is evident and Switzerland was no longer a low-wage country by World War I, but in comparison Swiss purchasing power was not higher than abroad. Living standards increased steadily until

1950, with noticeable but short-term decreases or stagnation during the two world wars and the Great Depression. Weight and BMI reflect the immediate nutritional conditions while height is the result of the cumulative net nutrition over the entire growth years. Thus, it is interesting to analyse how weight and BMI have developed relative to the increase in height and other well-being indicators during an erratic period when war, economic growth and economic crisis alternated and the welfare state expanded (Rosenberg 2012).

The short-termed impact of World War I on birth weights, as well as on height and upper arm circumference of school children has already been analysed for some regions in Switzerland (Staub 2016; Floris, Staub, and Woitek 2016). In addition, the development of height, BMI, chest circumference and right upper arm circumference of conscripts has been studied for cross-sectional Swiss conscripts data (years: 1875-1879, 1933-1939, 1994-2014) (Staub et al. 2016; Schoch, Staub, and Pfister 2012; Staub et al. 2010). A rising trend in BMI values was observed over the course of the 20th century using three cross-sections from the 1870s, the 1930s and 2014: average BMI among conscripts raised from 20.63 kg/m2 in the 1870s to 23.29 kg/m2 in 2014 (Staub et al. 2016; Schoch, Staub, and Pfister 2012; Staub et al. 2010). In the 1870s and 1930s, weight and BMI values were almost symmetrically distributed (Staub et al. 2016). In the 1870s, 12.1% of the young Swiss conscripts were underweight, 1,6% overweight, and 0.1% obese by modern standards, whereas in 2014 5.5% were underweight, 18.4% overweight and 5.7% obese (Staub et al. 2016).

In the case of these anthropometric data analysed for Switzerland, however, there is a large time gap in the data for body weight measurements between 1880 and 1932 (the army did not consider body weight to be an important measure of nutritional status and military fitness at the time). In this paper, we aim to fill this weight gap and estimate weight and BMI based on height, chest circumference and mid upper arm circumference measures of Swiss conscripts in the city of Zurich for each year between 1904 to 1932. We used existing anthropometric prediction equations from the literature and developed equations that we tested and validated on our 1933 to 1951 dataset, which includes body weight data. This makes it possible to investigate changes in mean weight and BMI in the first half of the 20th century for a representative sample of young urban adults on a yearly basis.

2. Methods

Data

We analyse yearly data of young men conscripted in the city of Zurich between 1904 and 1951. Since 1875, every 19-year-old male Swiss citizen has been called up for conscription (Kurz 1985). The anthropometric data were recorded during the medical examination for military fitness (regardless of whether the person was fit for military service or not). These records of the city's military command are kept in Zurich's city archives (records prior to 1904 were not preserved in the archives). The complete anthropometric data of 99,912 conscripts from the written military control books were transcribed in anonymised form (without name, exact birth date and residential address) during the course of a historical dissertation at the Department of History of the University of Zurich between years 2007 to 2012 (Floris 2016). Permission was granted by the archive of Zurich and data protection contracts were signed. According to the Federal Act on Research involving Human Beings and the Ethical Commission of the Canton of Zurich, no ethical approval is needed for anonymously collected or anonymised health-related historical data (HRA 1 January 2014, Art. 2).

The medical examination at recruitment was prescribed in details in military instructions manuals (Schweizerische Armee 1887; 1932; 1941; 1952). The standardised procedure did not change over time. The procedure started with the measurement of height, followed by chest circumference and mid upper arm circumference and ended with the measurement of weight. However, weight was only measured from 1875 to 1879 and then again after 1932. Height was recorded with a portable device. Participants stood flat on their bare feet with the heels together and heels and the back of head touching the measuring rod. For chest circumference, the measuring tape was set snug around the naked chest in a horizontal line just below the nipples. The measurement was taken in between two breaths. Mid upper arm circumference was measured in the middle of the extended right upper arm. Participants were weighed while wearing trousers or underwear, presumably with a mechanical scale.

Since military service was and still is mandatory in Switzerland, we have a representative sample of the 19-year-old Swiss men living in the city of Zurich. A previous study estimated that in the conscription years 2004 to 2012, at least 91 per cent of the birth cohorts were recorded in the conscription data (Panczak et al. 2013), and this coverage was presumably even higher in the first half of the 20th century (Schoch, Staub, and Pfister 2012). We estimate a coverage of > 88 per cent for the city of Zurich in the census and conscription year 1920. For this paper, conscripts age 22 or older (10,438 (10.4%)) were excluded, as they are not considered regular conscripts and appeared at conscription with long delays. 5 conscripts older than 22 are excluded from the 1933 data (min) and 523 are excluded from the 1932 data (max), on average 217 conscripts are excluded per year.

On average, 1930 conscripts were measured per year (min 1126; max 3555). The number of conscripts per year increased over time because of increasing population. The legally stipulated age for recruitment was 19 between 1904-1951. Therefore, most of the conscripts in the dataset were aged between 19-20 (56 percent of all conscripts in our dataset, see Appendix Table 5). There were, however, deviations in this legal regulation during the period of observation (Floris 2016). In 1919 there was only limited conscription of old pending cases (n = 318). This was due to the influenza epidemic of 1918 and military budget issues after the war. Regular conscription took place from 1920, and until 1924, the majority of conscripts were 20 years old. The conscription age gradually returned to 19 from 1925 on. In 1928 about the same number of 19- and 20-year-olds were conscripted, and in 1930 only 19-year-olds were conscripted. In 1939 two conscription rounds took place: a regular one from February to July, and a war-related one in the winter of 1939/40 (November/February). During the war the conscription age was 18. In 1946 (n = 363), as in 1919, conscription did not occur. Conscription age returned to 19 from 1947 onwards. Comparisons between cohorts should bear in mind these differences in conscription age. We do not know the exact date of birth of the conscripts. The age variable is based on the difference between the year of conscription and the year of birth. The chronological age difference of two 19-year-olds in our dataset can therefore be one year. This paper includes the anthropometric data of 88,792 conscripts obtained each year between 1904-1951, with the exception of 1919 and 1946.

Conscripts' occupations were recorded during conscription. We used this information to assign each conscript to a social stratum on the basis of Schüren's classification (Schüren 1989), which is based on criteria such as typical income, wealth and prestige of the occupation. This occupational social hierarchy consists of three levels: low, middle and upper socioeconomic position (SEP). The SEP of a conscript is a good proxy for socio-economic background (Schoch, Staub, and Pfister 2012). In our dataset 50,538 (56.9%) conscripts had a low SEP, 24,979 (28.1%) a middle SEP and 11,520 (13.0%) an upper SEP. 1755 (2.0%) remaining conscripts were either farmers, lacked an occupation or could not be assigned to a specific SEP.

The lower SEP group consists of day labourers, unskilled and skilled workers. The middle SEP group consists of commercial employees, white-collar workers, and lower civil servants. The upper SEP group consists of students in higher education schools and universities. At the beginning of our observation period, 50 to 55 percent of the conscripts are in the lower SEP group. The share of the lower SEP group increases to 60 to 65 percent in the 1920s. This is equivalent to an increase of 250 to 500 conscripts. 30 to 35 percent of the conscripts are in the middle SEP group. In the 1920s the share decreases to 25 percent. The share of the upper SEP group remains constant over time (Figure 6).

Reconstruction based on equations from the literature

The measurement of mid upper arm circumference allows for a fast estimation of malnourishment and BMI, even though there is no universally accepted cut-off value as a screening criterion for identifying severe acute malnutrition (Tang et al. 2013). For adults and elderly people, the available equations differ in

the variables used for weight estimations and they show different degrees of accuracy (Balode et al. 2015; Melo Ferreira et al. 2014). Our literature review found seven prediction equations from six publications (Table 1) that are based on the same variables that we use (height, chest circumference, mid upper arm circumference). Sultana et al. (2015), Powell-Tuck and Hennessy (2003), and Benítez Brito et al. (2016) used mid upper arm circumference to calculate BMI (or vice versa), partially corrected for age. Even though all of these studies measured mid upper arm circumference at the midpoint between olecranon and acromion on the non-dominant (or left) side, equations to calculate BMI using this data vary considerably. Cattermole et al. (2017) calculated weight using a formula with right mid upper arm circumference. Ostechega et al. (2004) provides a formula for estimating mid upper arm circumference using weight, height and age; we rearranged this equation to make weight the subject of the formula. Chest circumference and height are used in the equation introduced by Chittawatanarat et al. (2012).

Table 1: Equations from the Literature

Reconstruction based on own equations

We developed weight and BMI regression equations using the conscription records from 1933 to 1938 (11,223 conscripts, 12.6% of the total dataset). These are the earliest years in these records that include weight measurements. We performed stratified random sampling to divide this dataset into a training dataset n = 5609 and a test dataset n = 5614 (using the sample_frac() function from the R dplyr package). We stratified according to SEP, age and measurement year (=conscription year). Summary statistics for height for the training and the test datasets are reported in Table 6 in the appendix**.** First, we estimated three simple linear regression equations on the training dataset. The dependent variable weight was regressed on each predictor variable separately (height, chest circumference, mid upper arm circumference, see the resulting regression equations in Table 7 in the appendix). In a second step we predicted weight for each conscript on the basis of those three regression equations, which resulted in three weight estimates per conscript. Finally, in a third step we calculated the arithmetic mean of those three predicted weight values. The basic idea behind this procedure is that every anthropometric predictor variable is correlated with weight. Both the accuracy of the predictive value, i.e. how close each prediction value is to the actual value, and the precision of the three prediction values, i.e. how close the prediction values are to each other, will differ, but the arithmetic mean of those three predicted values will be quite accurate, as the error should cancel out (Wells et al. 2009). We also predicted weight using multiple linear regression equations that include all combinations of our predictor variables. The same procedure was used to directly predict and estimate BMI values.

The resulting equation were tested on the test dataset 1933-1938. All equations were further validated on the conscription years 1947-1951 (where weight was also available) to see if they were accurate in a different time period. Finally, we compared our results with the equations from the literature. We used two criteria to evaluate the accuracy of the predicted values. First, the arithmetic mean of the

estimated values should not differ more than 1kg from the true mean weight in the dataset or 0.5kg/m2 from the true BMI values. Second, more than 85% of the estimated values should lie within a 10% interval around the true value. The second criterion focuses on the individual estimations, while the first criterion focuses on an accurate average estimation. We used the multiple regression equations with all predictor variables to estimate the missing weight (WCAH equation) and BMI (BMICAH equation) between 1904 and 1932. Both equations performed better in regards to the second criterion than the first. Figure 8 and Figure 9 in the appendix show scatterplots and Bland-Altman-plots using the WCAH equation for weight estimation and the BMICAH equation for BMI estimation.

3. Results

Descriptive results of measured data

In Figure 1 we show changes in average for height, chest circumference and mid upper arm circumference between 1904 and 1951, as well as for weight and BMI between 1933 and 1951 (for summary statistics for selected years see Table 9 in the appendix). Over this time period average height increased steadily from 167.2cm (95% CI: 166.7 – 167.6cm) to 173.4cm (95% CI 173.2 – 173.7cm), and chest circumference from 84.6cm (95% CI 84.3 - 84.9cm) to 90.0cm (95% CI 89.9 – 90.2cm). There was a less pronounced increase in average mid upper arm circumference from 24.75cm (95% CI: 24.64 – 24.86cm) to 25.77cm (95% CI: 25.69 – 25.84cm). During both world wars, chest and mid upper arm circumference decreased while height stagnated.

Both average weight and BMI decreased during the Great Depression and World War II. After the war, average weight returned to the pre-war and pre-Great Depression level (1933: 64.03kg, 95% CI: 63.69 – 64.37kg; 1951: 63.90kg, 95% CI: 63.62 – 64.18kg). BMI also recovered after the war but the pre-crisis level of 1933 had not been reached by 1951 (1933: 21.79kg/m2, 95% CI: 21.70 – 21.89kg/m2; 1951: 21.23kg/m2, 95% CI: 21.15 – 21.31kg/m2). In 1933, 54 conscripts (3.02%) had a BMI below 18.5kg/m2, 1642 (91.73%) between 18.5 and 25kg/m2, and 93 (5.20%) above 25.0 kg/m2. The percentage distribution was similar in 1951 (see Table 10 in the appendix). Histograms and kernel density estimation curves for height, chest circumference, mid upper arm circumference, weight and BMI in 1933 are shown in Figure 11 in the appendix. All distributions appear symmetrical, and the height distribution in particular indicates heaping at numbers ending in 0 or 5.

Figure 1: Mean changes in anthropometric measures among conscripts 1904 to 1951 (measured values)

Estimate accuracy, test and validation

Next, we evaluated the accuracy of our own estimation equations and compared them with the estimates using the equations from the literature. The results for our own equation are presented in Table 2, and those from the literature in Table 11 in the appendix. Our own estimates of the mean weight are more accurate than those resulting from the literature equations. We under or overestimate the true mean weight by less than 3% (less than 1.9kg difference) in the test dataset (1933-1938) and validation dataset (1947-1951). One of our own equations fails to meet the second criterion (more than 85% of the estimates within a 10% interval around the true value). None of the equations from the literature meet the second criterion.

The results for our own equation for BMI are presented in Table 3 and those of the literature in Table 12 in the appendix. Our own estimates under or overestimate the true mean BMI by less than 3% (less than 0.65kg/m2 difference) in the test dataset (1933-1938) and the validation dataset (1947-1951). Two estimations do not meet the second criterion (more than 85% of the estimates within a 10% interval around the true value). The literature BMI estimation equations work better than those for weight estimation, but only the Powell-Tuck and Hennessy (2003) (not age corrected) equation for BMI meets both criteria in both datasets.

Table 2: Own equation estimation accuracy weight (kg)

Table 3: Own equation estimation accuracy BMI (kg/m2)

For the trend estimations of weight and BMI presented in the next section, we used the equations that performed best according to the second criterion (more than 85% of the estimates within a 10% interval around the true value). For the weight reconstruction we used our WCAH equation and for BMI reconstruction we used our BMICAH equation. The agreement between measured and estimated weight and BMI values from the test data set 1933-1938 is presented in the Appendix Figures 4 and 5. Although there is some variation in the accuracy of individual values, the overall mean is predicted with precision (Appendix Figure 5). These Bland-Altman plots also show that we underestimate large weight and BMI values in particular (the smoothed trend lines deviate towards lower estimated than measured values). That is why we slightly underestimate the measured mean value in a small decimal range.

Estimated trends of weight and BMI

Figure 2 shows estimates of mean weight for the entire period 1904 to 1951, calculated with our own equation WCAH (the equation with the best performance regarding the second criterion: Numbers of values in a 10 percent range). The figure includes the mean weight values of the dataset with recorded weights (1933 to 1951). Mean weight increased over time. The increase was most pronounced in the 1920s, while there was a decrease during the 1930s and during both world wars. In addition, the figure shows mean weight estimates (WCAH equation) for the three socioeconomic groups (SEP) from 1904 to 1951. The lower SEP and middle SEP groups have similar mean weights. In 1904, the upper SEP group was about 5kg heavier than the other groups. The difference decreased steadily and in 1951 the upper SEP group was only slightly heavier than the other groups. Mean weight increased over time by 8kg for the low and middle SEP groups, and 5kg for the upper SEP. The negative impact of both world wars is visible for all three groups.

Figure 2: Estimated mean weight and SEP differentiated mean weight 1904-1951 (WCAH equation)

Figure 3 shows average BMI estimates for the time period 1904 to 1951. For the estimation, the BMICAH equation was used (the equation with the best performance regarding the second criterion: No. of

values in a 10 percent range). The figure includes the mean BMI values of the dataset with recorded weights (1933 to 1951). BMI increased slightly over time, with increase being most pronounced in the 1920s. Mean BMI decreased in both world wars and in the 1930s. In addition, the figure shows mean BMI estimates (BMICAH equation) for the three socioeconomic groups (SEP) from 1904 to 1951. The lower SEP group had the highest BMI values. The middle and upper SEP show similar average BMI values. However, average BMI values of the upper SEP group were generally slightly higher. Again, the impact of both world wars is visible for all three groups.

Figure 3: Estimated mean BMI and SEP differentiated estimated mean BMI 1904-1951 (BMICAH equation)

4. Discussion

This paper estimates weight and BMI values based on height, chest circumference and mid upper arm circumference. First, we linearly regressed BMI and weight using different combinations of predictor variables with a training dataset from the 1930s. Second, we tested and validated the resulting equations on a test dataset and a different validation dataset. We then compared our estimates with estimates using equations proposed in the literature. We used the best equation to estimate missing weight and BMI values from 1904 to 1932. We show that weight and BMI can be estimated with accuracy using height, chest circumference and mid upper arm circumference. It allows us to reconstruct changes and trends in weight and BMI for a young, healthy, urban male population and for SEP subgroups. And it allows us to assess the impact of World War I on weight and BMI.

Data

The data was recorded as part of the compulsory military conscription in Switzerland from 1904 to 1951. The measurement procedures were described in detail in instruction books and remained the same for the whole period. Since several people carried out the procedure, a high compliancy with the protocol can be assumed. However, the data were not recorded for scientific purpose. Therefore, no stated effort was made to reduce possible measurement error. But the following of a standardized examination procedure would have minimized measurement errors.

We used a large representative sample of young Swiss males (between 18 and 21 years old) who lived in an urban environment. The changes over time are mainly caused by changes in the environment and not by changes of the study population. The high comparability of the study population over time is important for being able to obtain accurate estimation equations. Migration patterns, however, could still have had an impact on the study population. It is especially true for the years before World War I when immigration to Switzerland was more important than in the interwar period and during both world wars. The results in this paper apply only to the particular group of young males with Swiss citizenship living in an urban area.

Zurich attracted a constant rate of internal migration. The net migration gain was driven by Swiss citizens from other cantons (Statistisches Amt der Stadt Zürich 1951). The most important age classes were 15-19, 20-24, and 25-29 years (Statistisches Amt der Stadt Zürich 1929; 1951). Rough calculations give a worst-case scenario of 10 percent more conscripts annually due to internal migration. We are not able to assess the potential bias. We know whether those conscripts came from rural or urban areas, but not the age at which a conscript settled in Zurich. In Switzerland, place of birth is usually not recorded in official documents. Thus, we are not able to differentiate between the immigrant conscripts from those born in Zurich. The changes in the SEP distribution reflect changes in society and are probably related to the issue of internal migration. The majority of people worked in the industrial sector or were tradesmen

(Statistisches Amt der Stadt Zürich 1961). We assume that a large proportion of the internal migrants worked in these professions.

Equations

The anthropometric prediction equations found in the literature did not show satisfying results for our sample. Especially the weights were not precisely estimated. This is mainly because those equations were developed on different study populations. There is consensus in the literature that weight estimation formulas established for a specific population cannot be expected to work with the same precision for other populations (Sebo et al. 2015). Sample size, age of the study population, and measurement methods (e.g. measured, estimated, self-reported) are other factors that could explain why the application of the equations from the literature has led to imprecise results (Preedy 2012). An additional difference to other studies is that we used a historical sample. Most equations from the literature were developed in the last three decades. The equations from the literature worked better for the BMI estimation. With the exception of the Powell-Tuck and Hennessy (2003) equation, they were, however, still less accurate than our own. We also analyzed whether our equations work in a time of crisis. Our two main equations for weight and BMI provide very precise estimates during the Second World War (see Table 15 in the appendix).

We did not correct for age in our estimations. There are usually not enough conscripts in the age classes to allow a meaningful comparison. The sample size is large enough only for the years 1926 to 1929 for both 19- and 20-years old conscripts as well as for the year 1939 for 18- and 19-years old conscripts. We see only small differences in the anthropometric measures across age classes in those years (Table 13 in the appendix and Figure 7). There are only small differences in the regression estimates when we control for age (Table 14 in the appendix).

We over-estimate weights 1939, 1940, and 1941 as well as 1949, 1950, and 1951. Those two periods have values for height that are slightly above the long-term trend. Perhaps these taller conscripts did not in reality increase their weight exactly in proportion to their height. Regarding the weights before 1933 we see that the conscripts between 1925 and 1933 have height values falling slightly below the long-term trend. This might indicate a group with slightly shorter leg length, and hence greater weight than would be expected for their height. Overall, our weight estimates fit well with the lower weight average of 56.1 kg for Swiss conscripts in the conscription years 1875-1879 (Staub et al. 2016).

Reconstruction

All variables increased from 1904 to 1951. Height showed a steady increase but it also stagnated during both world wars. As height is determined by the stature of previous generations and nutritional status during childhood, a smooth increasing curve was to be expected according to the literature (Hatton 2014; Baten and Blum 2012; Hatton and Bray 2010). For example, the dip in height around 1935 may reflect poor

growth in the cohort that were *in utero or infants* during World War I. This may relate to adverse effects on maternal nutritional status of psychosocial stress or limited food rations.

In general, the standard of living increased (Figure 4). With the exception of the two world wars and the 1930s, real wages rose steadily. The real GDP p.c. followed this trend. In the 19th century, infant mortality was higher in the cities than in rural areas of Switzerland (Head-König 1998; Schoch, Staub, and Pfister 2012). Due to the rapid modernization of sewage and water supply systems, the modernization of the healthcare system, and the more rapid spread of hygienic and sanitary measures in urban centres, the situation reversed between 1870 and 1914 (Lorenzetti and Meffre 2005; Floris and Staub 2019; Floris, Staub, et al. 2019), with mortality decreasing more rapidly in the cities. Relative to other European countries, Switzerland was marked by an above average increase in GDP p. c. but only an average increase in real wages, life expectancy at birth, and average height (Floris, Höpflinger, et al. 2019).

Figure 4: Trends of real GDP per capita, average real wage, and infant mortality rates in Zurich. Panel A) District of Zurich real GDP data from Stohr (2016a; 2016b) and annual average real wages for Zurich and Basel combined from Studer (2008) and Studer and Schuppli (2008). Panel B) Infant mortality 5-year average data from Statistisches Amt der Stadt Zürich (1951)

Working class families in Switzerland consumed mainly milk and dairy products, meat and fish, bread and cereal products, and potatoes (Tanner 1999, 151–55). According to Tanner, they drank considerably more milk than workers in Germany, Austria, and England and also ate relatively large amounts of bread. They consumed about the same amount of butter and cheese, but considerably less meat (Tanner 1999, 151–55). In 1912, Zurich workers spent about 40 percent of their income on food (Swiss Federal Statistical Office 2013a), whereas in 1953 the proportion was 30 percent. Milk, bread, potato, and meat consumption also dominated in Zurich (Table 4). The doubling of annual per capita milk consumption in Switzerland between 1875 and 1900 contributed to the increase in average height in the subsequent years (Staub and Rühli 2013). Other factors that impact the endocrine system and that contributed to the increase in height were the iodine-deficiency and rickets prophylaxis campaigns (Staub and Rühli 2013): Starting in the 1920s, school children received weekly iodine pills and iodized table salt was introduced; in the 1930s school children received vitamin D pills.

Table 4: Consumption per family of selected foodstuff in working-class households in the city of Zurich

There is a marked decrease in weight and BMI from 1916 to 1918. This reflects the worsening food condition during the First World War. The historical literature suggests that the food supply was stable in the first two years of the war but became limited thereafter (Rossfeld and Straumann 2008). The size of the decrease in average weight (-2.1kg 1914 compared to 1918) indicates the worsening standard of living. Within two years of the war ending, a recovery to pre-war levels is visible. For BMI there was another

decrease from 1930 to 1945. During the 1930s, this trend was mostly due to the increase in height and stagnation of weight. Since BMI has squared height in the denominator, even small increases in height without corresponding increases in weight lower BMI significantly. The decrease in the 1940s is clearly related the Second World War, and particularly towards the end of the war, the average BMI of the conscripts seems to have suffered, reflecting the increasingly poor food situation (decline in imports and reduced rations). The decreased BMI at the beginning of the war, in 1940, could be related both to this cohort having received poorer nutrition early in life, along with the 1940s war-related change in diet due to the incipient rationing (reduced fat, meat and egg intake compared to pre-war nutrition) (Tanner 1999; Fleisch 1947). The decrease in weight and BMI in the Second World War was, however, less pronounced than in the First World War as the authorities were better prepared for a war. Plans for a possible war economy began being made in 1936 (Cottier 2014). In comparison to the First World War, soldiers received compensation for their loss of earnings, rationing was implemented from the beginning of the war, and possible trade-offs with other policy measures were mitigated and coordinated as well as possible (Kreis 2011; Jost 1998). A year after the Second World War, the pre-war level of weight and BMI was reached again.

The upper SEP group was heavier in 1904 than the other groups (Upper SEP: 62.62kg, 95% CI: 61.30 – 63.94kg; middle SEP: 57.55kg, 95% CI: 56.84 – 58.27kg; lower SEP: 57.41kg, 95% CI: 56.81 – 58.01kg). In 1951, the difference was less than 2 kg (Upper SEP: 66.40kg, 95% CI: 65.57 – 67.23kg; middle SEP: 64.93kg, 95% CI: 64.47 – 65.40kg; lower SEP: 65.40kg, 95% CI: 65.07 – 65.72kg). This difference cannot be observed for BMI. The main reason is that people in the upper SEP group were taller and thus also heavier. This could be due to the better food supply this group had. However, habitual physical activity and adaptation to the work environment, as well as differences in job profiles can bring out certain physical characteristics and could thus explain different SEP pattern (Schoch, Staub, and Pfister 2012). However, the lower and middle SEP groups also caught up with the upper SEP group in terms of height between 1904 and 1951, although the reduction of the difference between height levels is slower than for weight and the difference between the lower and middle group remains constant (Figure 5).

Figure 5: SEP differentiated mean height 1904-1951

We are aware that using a statistical measure of a population based only on the mean may not fully capture the true nature of changes in the population (Razak, Davey Smith, and Subramanian 2016). However, in the Swiss case, we know that the widening of the BMI distribution appeared after the 1950s and that BMI was almost symmetrically distributed in the 1870s and 1930s (Staub et al. 2018; 2016; 2010), which makes the problem less relevant to this paper. Furthermore, in this paper we cannot estimate what effect the Spanish flu may have had. Thus, we do not know if this negative health shock had a *selection* or a *scarring* effect on the later average height of the population (Deaton 2007). Another limitation of our approach is that body proportions can change.

This study offers the first reconstruction and estimation of mean body weights and BMI values on a yearly basis for a representative sample of a historical population across the first half of the 20th century. Even though our estimation equations are based on a specific population, our approach could be replicated for other historical populations to obtain more information on how nutritional status changed over time. Not only can weight and BMI be predicted based on human remains, but also estimated relatively accurately in living individuals if other anthropometric measurements are available and the sample is large enough. Thus, we propose making greater use of these opportunities in historical anthropometry.

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Tables

Table 1: Equations from the Literature

Benítez Brito et al. 2016: BMI

Aim	Cut-off point of mid upper arm circumference (MUAC) for BMI < 18.5
Equation	BMI = − 0.042 + 0.873 x MUAC (cm)
Participants	n = 1373, hospitalized adults

Sultana et al. 2015: BMI

Aim	Cut-off point of mid upper arm circumference (MUAC) for BMI < 18.5
Equation	MUAC (cm) = 10.481 + 0.718 x BMI
Participants	n = 650, adults

Powell-Tuck and Hennessy 2003: BMI (2 equations)

Aim	Comparison of mid upper arm circumference (MUAC), BMI, weight loss
Equation	BMI=1.01 x MUAC (cm) -4.7
Equation	BMI=1.02 x MUAC + 0.03 x age - 6.7
Participants	n = 603, hospitalized adults

Cattermole et al. 2017: Weight

Aim	Mid upper arm circumference (MUAC) for weight estimation
Equation	Weight (kg) = 3.8484×MUAC (cm) - 46.8585
Participants	n=17,520, NHANES (2011-2012 and 2009-2010), 11-80 years

Chittawatanarat et al. 2012: Weight

Aim	Chest circumference (ChC) and height (Ht) for weight (Wt) estimation
Equation	Wt = 1.12 x ChC (cm) + 0.39 x Ht (cm) - 100.4
Participants	n=2000, adults

Ostchega et al. 2004: Weight

Aim	Weight (Wt), height (Ht) and age for mid upper arm circumference (MUAC) estimation
Equation	MUAC (cm)= 31.76749 + 0.22626 x Wt (kg) – 0.10109 x Ht (cm) + 0.05092 x age (years) – 0.00081813 x age^2
Participants	Participants: n=14,690, adults, NHANES III and 1999-2000

Table 2: Own equation estimation accuracy weight (kg)

	Test dataset 1933-1938	Validation dataset 1947-1951
Average of based on 3 simple regression equations (WChest, WArm, WHeight)		
Actual mean	63.25	63.58
Predicted mean	63.27	64.27
Difference	-0.02	-0.69
No. of values in a 10 percent range (in %)	86.21	84.92
Weight = Intercept + Chest + Arm + Height (WCAH)		
Actual mean	63.25	63.58
Predicted mean	63.25	64.85
Difference	-0.01	-1.27
No. of values in a 10 percent range (in %)	94.59	91.84
Weight = Intercept + Chest + Arm (WCA)		
Actual mean	63.25	63.58
Predicted mean	63.29	64.40
Difference	-0.04	-0.82
No. of values in a 10 percent range (in %)	85.39	84.43
Weight = Intercept + Chest + Height (WCH)		
Actual mean	63.25	63.58
Predicted mean	63.36	65.36
Difference	-0.11	-1.78
No. of values in a 10 percent range (in %)	85.62	78.29
Weight = Intercept + Arm + Height (WAH)		
Actual mean	63.25	63.58
Predicted mean	63.19	64.41
Difference	0.06	-0.83
No. of values in a 10 percent range (in %)	91.67	90.04

Table 3: Own equation estimation accuracy BMI (kg/m2)

	Test dataset 1933-1938	Validation dataset 1947-1951
Average of based on 3 simple regression equations (BMIChest, BMIArm, BMIHeight)		
Actual mean	21.49	21.14
Predicted mean	21.50	21.62
Difference	-0.01	-0.48
No. of values in a 10 percent range (in %)	85.72	79.50
BMI = Intercept + Chest + Arm + Height (BMICAH)		
Actual mean	21.49	21.14
Predicted mean	21.49	21.56
Difference	-0.00	-0.42
No. of values in a 10 percent range (in %)	94.79	92.06
BMI = Intercept + Chest + Arm (BMICA)		
Actual mean	21.49	21.14
Predicted mean	21.49	21.66
Difference	0.01	-0.52
No. of values in a 10 percent range (in %)	91.53	86.46
BMI = Intercept + Chest + Height (BMICH)		
Actual mean	21.49	21.14
Predicted mean	21.53	21.73
Difference	-0.04	-0.59
No. of values in a 10 percent range (in %)	85.62	78.06
BMI = Intercept + Arm + Height (BMIAH)		
Actual mean	21.49	21.14
Predicted mean	21.47	21.41
Difference	0.02	-0.27
No. of values in a 10 percent range (in %)	91.86	90.06

Table 4: Consumption per family of selected foodstuff in working-class households in the city of Zurich

Year	Bread (kg)	Flour (kg)	Pasta (kg)	Potatoes (kg)	Vegetables and legumes (kg)	Fruits and nuts (kg)	Milk and cream (l)	Butter and cheese (kg)	Meat (kg)
1912	336	24	26	160		150	910	28	108
1919	310	28	29	235		304	965	29	76
1920	337	28	30	208	135	269	967	45	78
1921	359	30	29	236	120	202	1060	39	85
1922	340	32	29	213		311	1120	44	110
1923	423	33	35	230		215	1132	42	111
1936/37	242	25	26	177	163	233	752	40	96
1943	314	19	16	421	200	349	793	42	77
1946	270	24	31	435	167	374	769	37	75
1949	238	24	30	262	164	321	818	42	87
1953	252	24	34	203	180	335	769	45	88

Source: (Swiss Federal Statistical Office 2013b)

Figure 1: Mean changes in anthropometric measures among conscripts 1904 to 1951 (measured values)
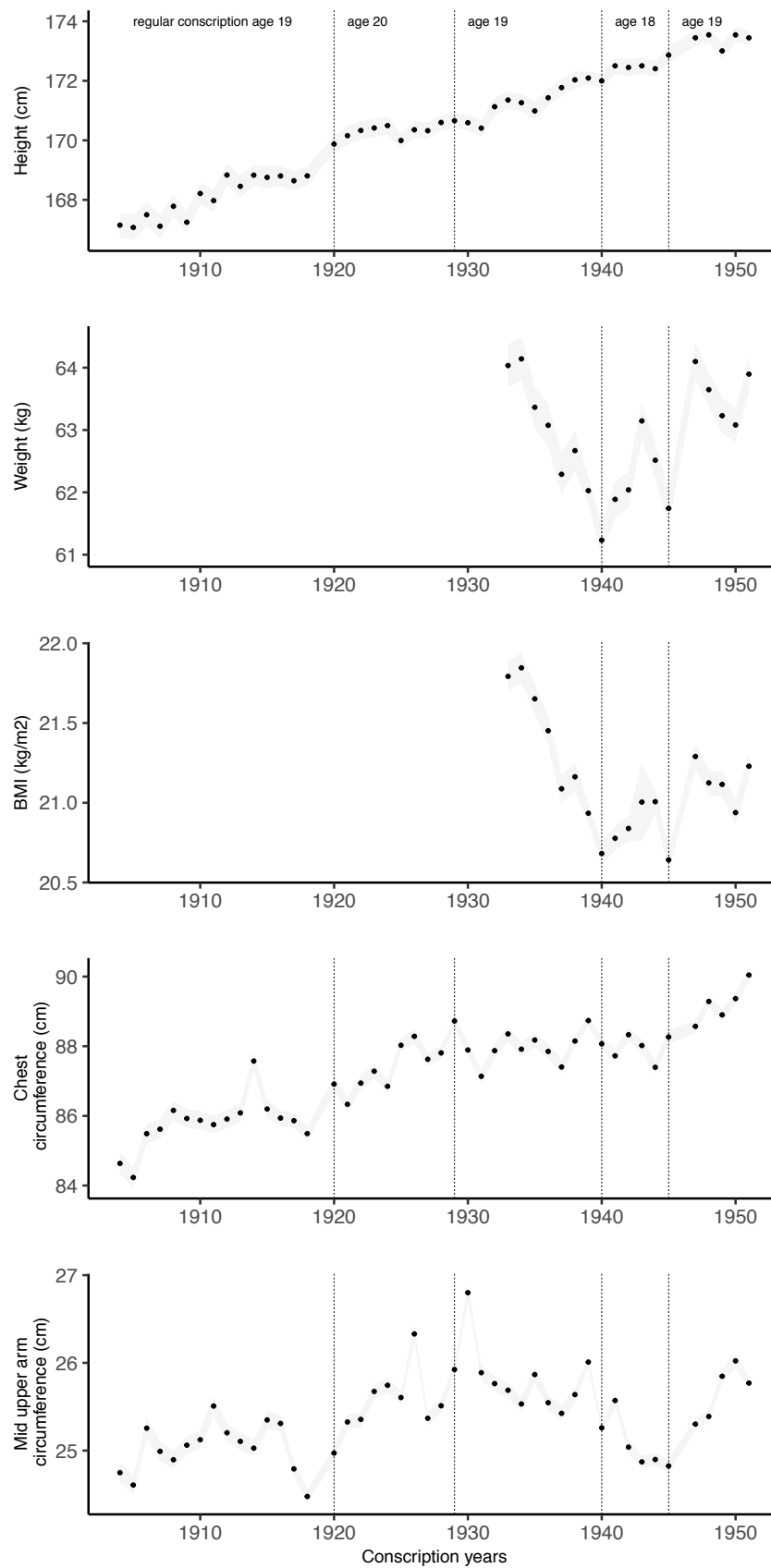
Figure 2: Estimated mean weight and SEP differentiated mean weight 1904-1951 (WCAH equation)
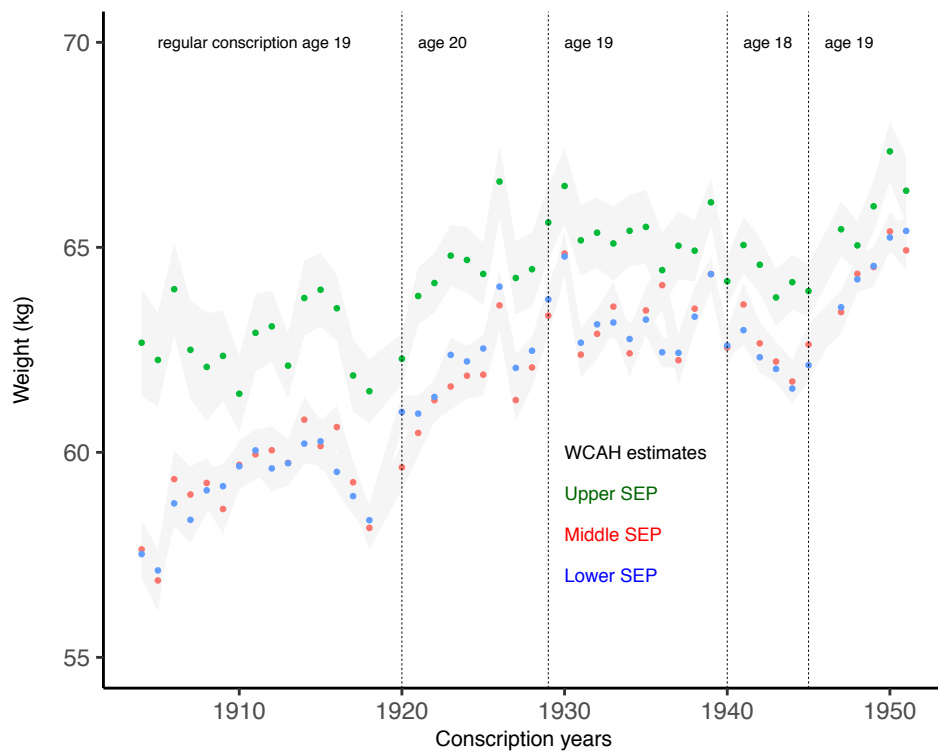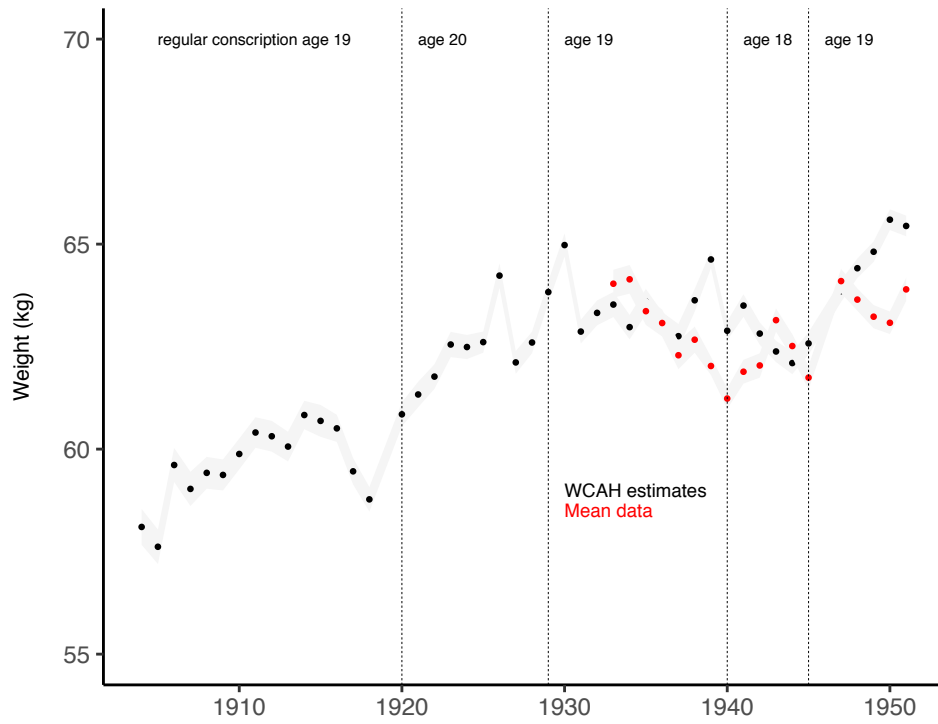
Figure 3: Estimated mean BMI and SEP differentiated estimated mean BMI 1904-1951 (BMICAH equation)
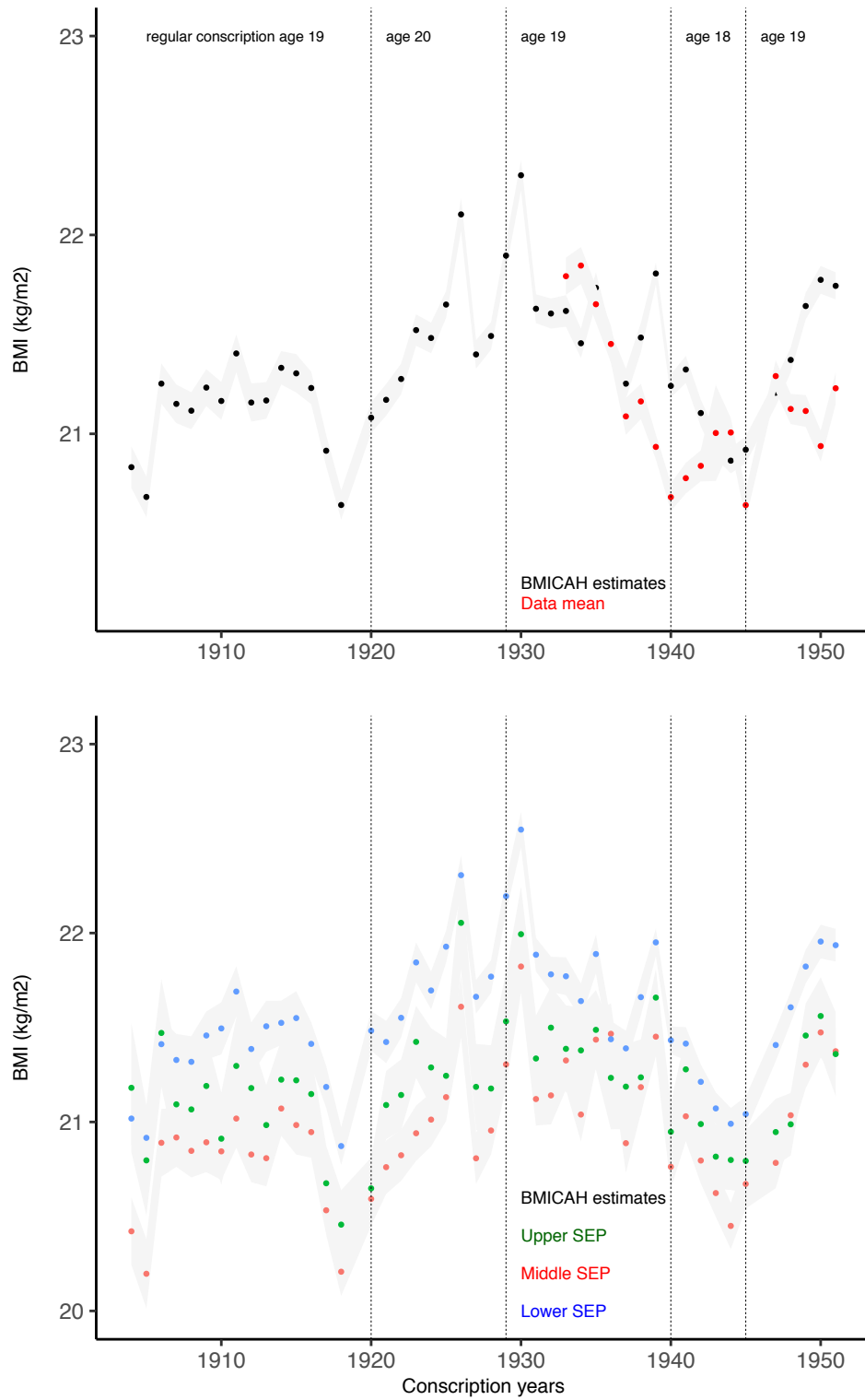
Figure 4: Trends of real GDP per capita, average real wage, and infant mortality rates in Zurich. Panel A) District of Zurich real GDP data from Stohr (2016a; 2016b) and annual average real wages for Zurich and Basel combined from Studer (2008) and Studer and Schuppli (2008). Panel B) Infant mortality 5-year average data from Statistisches Amt der Stadt Zürich (1951)
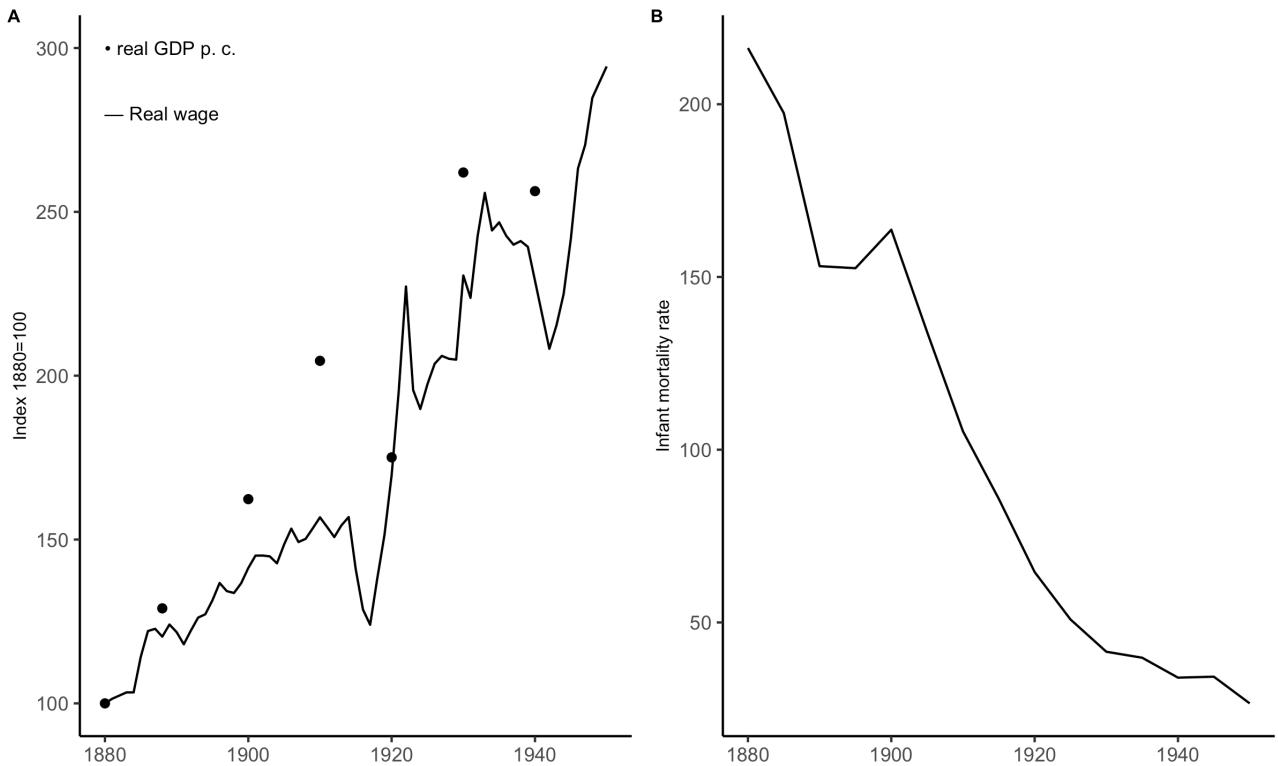
Figure 5: SEP differentiated mean height 1904-1951
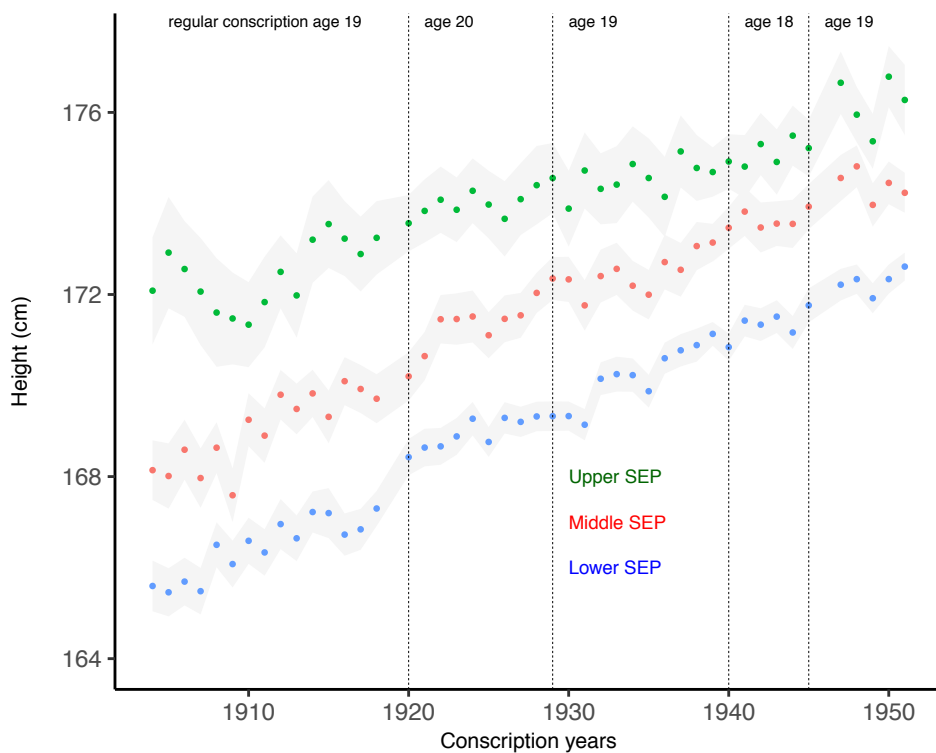
Figure 6: Shares of the occupational stratification groups over time

regular conscription age 19   age 20   age 19   age 18   age 19

lower SEP   middle SEP   upper SEP
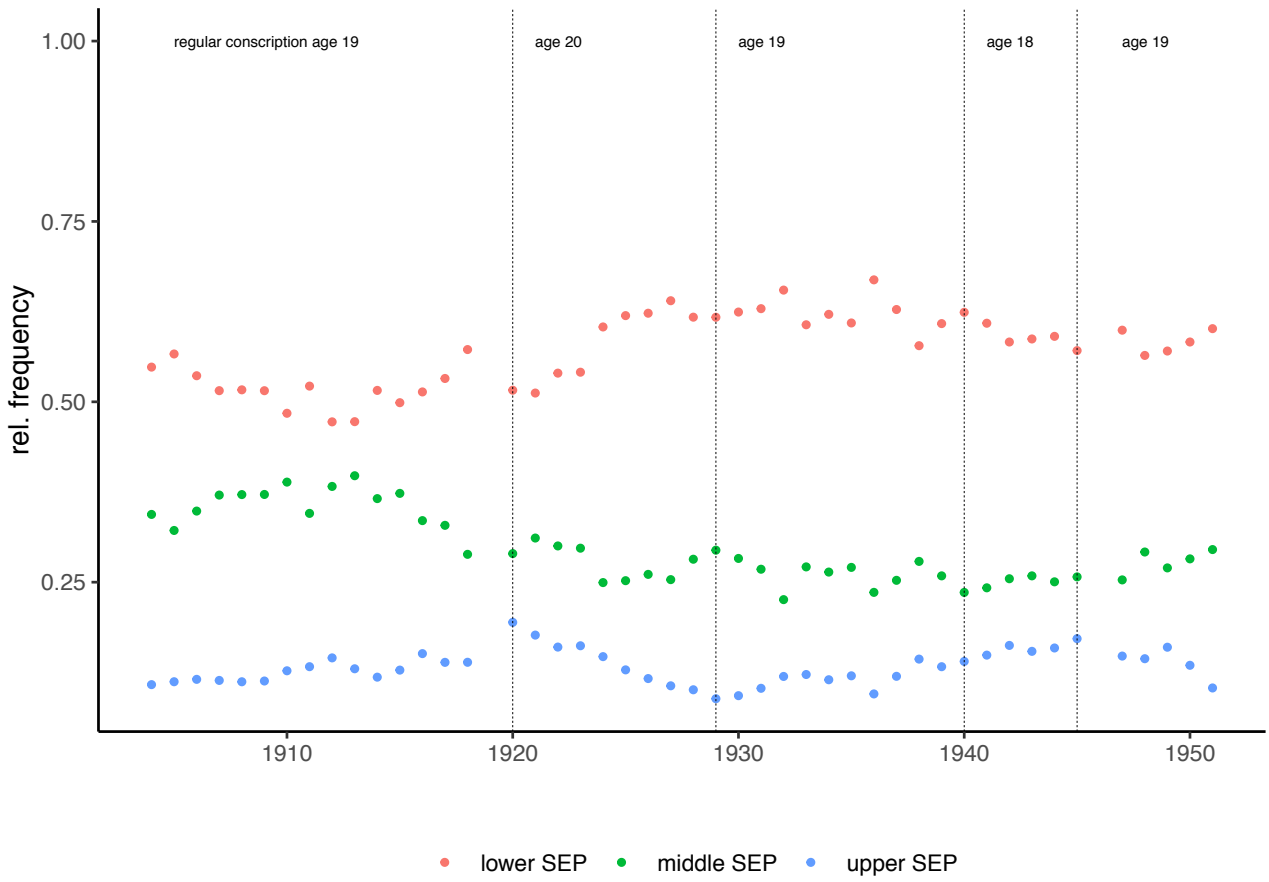
Appendix

Table 5: Overall age distribution at conscription 1904-1951

Age class	N	%
< 19	14524	16.4
[19-20)	49978	56.3
[20-21)	19736	22.2
21	4554	5.1

Table 6: Summary statistics train and test dataset (height cm)

	N	Mean	SD	Min	25%	Median	75%	Max	IQR
Training dataset 1933-1938									
Farmer	70	170.7	6.9	156.5	167.0	170.0	174.4	188.5	7.4
Low SEP	3414	170.5	6.1	148.0	166.5	170.5	174.5	201.0	8.0
Middle SEP	1448	172.4	6.2	142.0	168.0	172.5	176.5	197.0	8.5
Upper SEP	655	174.7	6.1	157.0	170.5	174.5	179.0	193.5	8.5
NA	22	173.4	8.3	154.5	169.1	173.8	179.5	186.0	10.4
Test dataset 1933-1938									
Farmer	73	171.1	7.5	155.0	166.0	171.0	176.0	190.0	10.0
Low SEP	3408	170.4	6.3	143.0	166.5	170.5	175.0	194.0	8.5
Middle SEP	1443	172.6	6.3	129.0	169.0	172.5	177.0	195.0	8.0
Upper SEP	660	174.6	6.0	157.0	170.5	174.5	178.5	197.0	8.0
NA	30	169.2	7.3	152.0	165.1	171.5	173.9	182.0	8.8

Table 7: Estimated regression equations weight

Training dataset 1933-1938				
Name: WHeight	**Estimate**	**SE**	**t value**	**p value**
Intercept	-49.52	2.16	-22.94	< 0.0001
Height	0.66	0.01	52.27	< 0.0001
R2	0.33			
Name: WChest				
Intercept	-44.95	1.27	-36.05	< 0.0001
Chest circumference	1.24	0.01	85.80	< 0.0001
R2	0.57			
Name: WHeight				
Intercept	-9.22	0.93	-9.88	< 0.0001
Upper arm circumference	2.83	0.04	77.88	< 0.0001
R2	0.52			
Name WCAH				
Intercept	-102.53	1.32	-77.43	< 0.0001
Chest circumference	0.50	0.01	34.39	< 0.0001
Upper arm circumference	1.81	0.03	55.84	< 0.0001
Height	0.44	0.01	55.98	< 0.0001
adj. R2	0.78			
Name: WCA				
Intercept	-48.43	1.13	-42.8	< 0.0001
Chest circumference	0.81	0.02	48.10	< 0.0001
Upper arm circumference	1.57	0.04	39.03	< 0.0001
adj. R2	0.66			
Name: WCH				
Intercept	-92.48	1.64	-56.46	< 0.0001
Chest circumference	1.03	0.01	74.15	< 0.0001
Height	0.38	0.01	39.19	< 0.0001
adj. R2	0.66			
Name: WAH				
Intercept	-94.38	1.43	-65.8	< 0.0001
Upper arm circumference	2.54	0.03	93.11	< 0.0001
Height	0.54	0.01	67.76	< 0.0001
adj. R2	0.73			

Rounded to two decimal places

Table 8: Estimated regression equations BMI

Name: BMIHeight	Estimate	SE	t value	p value
Intercept	26.00	0.73	35.64	< 0.0001
Height	-0.03	0.00	-6.18	< 0.0001
R2	0.01			
Name: BMIChest				
Intercept	-3.33	0.42	-7.85	< 0.0001
Chest circumference	0.28	0.00	58.62	< 0.0001
R2	0.38			
Name: BMIArm				
Intercept	0.38	0.24	1.55	0.12
Upper arm circumference	0.82	0.01	86.60	< 0.0001
R2	0.57			
Name: BMICAH				
Intercept	8.04	0.44	18.09	< 0.0001
Chest circumference	0.17	0.00	34.70	< 0.0001
Upper arm circumference	0.61	0.01	56.46	< 0.0001
Height	-0.10	0.00	-38.33	< 0.0001
adj. R2	0.68			
Name: BMICA				
Intercept	-4.39	0.34	-12.86	< 0.0001
Chest circumference	0.10	0.01	19.39	< 0.0001
Upper arm circumference	0.67	0.01	55.30	< 0.0001
adj. R2	0.60			
Name: BMICH				
Intercept	11.44	0.55	20.74	< 0.0001
Chest circumference	0.35	0.00	74.60	< 0.0001
Height	-0.12	0.00	-36.94	< 0.0001
adj. R2	0.50			
Name: BMIAH				
Intercept	10.80	0.48	22.40	< 0.0001
Upper arm circumference	0.86	0.01	93.94	< 0.0001
Height	-0.07	0.00	-24.67	< 0.0001
adj. R2	0.61			

Rounded to two decimal places

Table 9: Summary statistics

Year	N	Mean	SD	Min	Q1	Median	Q3	Max	IQR
				Height (cm)					
1910	1281	168.2	6.6	140.5	164.0	168.5	173.0	192.5	9.0
1920	1959	169.9	6.6	142.0	166.0	170.0	174.0	194.0	8.0
1933	1790	171.4	6.6	129.0	167.0	171.5	176.0	197.0	9.0
1940	3090	172.0	6.6	128.0	168.0	172.0	176.0	197.0	8.0
1951	2594	173.4	6.2	150.0	169.0	173.0	178.0	194.0	9.0
				Chest circumference (cm)					
1910	1281	85.9	4.7	68.0	83.0	86.0	89.0	107.0	6.0
1920	1959	86.9	5.0	52.0	84.0	87.0	90.0	108.0	6.0
1931	1790	88.4	4.8	68.0	85.0	88.0	91.0	112.0	6.0
1940	3090	88.1	4.6	68.0	85.0	88.0	91.0	108.0	6.0
1951	2594	90.0	4.5	65.0	87.0	90.0	93.0	116.0	6.0
				Mid upper arm circumference (cm)					
1910	1281	25.1	1.9	19.0	24.0	25.0	26.0	37.0	2.0
1920	1959	25.0	1.8	16.0	24.0	25.0	26.0	36.0	2.0
1931	1790	25.7	1.8	19.5	24.5	26.0	27.0	34.0	2.5
1940	3090	25.3	1.8	19.0	24.0	25.0	26.0	32.0	2.0
1951	2594	25.8	2.0	19.0	24.0	26.0	27.0	38.0	3.0
				Weight (kg)					
1933	1790	64.0	7.3	35.0	60.0	64.0	68.0	120	8.0
1940	3090	61.2	7.1	29.0	56.0	61.0	65.5	95.0	9.5
1951	2594	63.9	7.3	41.0	59.0	63.0	68.0	124.0	9.0
				BMI (kg/m^2)					
1933	1790	21.8	2.0	16.2	20.4	21.6	23.1	35.8	2.7
1940	3090	20.7	2.0	14.5	19.4	20.6	21.9	30.7	2.5
1951	2594	21.2	2.1	15.7	19.8	21.1	22.3	41.4	2.5

Table 10: BMI categories 1933 and 1951

	BMI categories (kg/m2)			
Conscription year	**< 18.5**	**[18.5-25)**	**[25-30)**	**> 30**
		Conscripts		
1933	54	1642	90	3
1951	162	2326	98	8
		Percentage		
1933	3.02	91.73	5.03	0.17
1951	6.25	89.67	3.78	0.31

Table 11: Literature equation estimation accuracy weight (kg)

	Test dataset 1933-1938	Validation dataset 1947-1951
Chittawanarat et al. 2012 estimation		
Actual mean	63.25	63.58
Predicted mean	65.06	67.19
Difference	-1.81	-3.61
No. of values in a 10 percent range (in %)	78.59	60.09
Cattermole et al. 2017 estimation		
Actual mean	63.25	63.58
Predicted mean	51.66	51.94
Difference	11.59	11.64
No. of values in a 10 percent range (in %)	16.63	18.38
Ostchega et al. 2004 estimation		
Actual mean	63.25	63.58
Predicted mean	46.40	47.56
Difference	16.87	16.03
No. of values in a 10 percent range (in %)	2.71	4.43

Table 12: Literature equation estimation accuracy BMI (kg/m2)

	Test dataset 1933-1938	Validation dataset 1947-1951
Benítez Brito et al. 2016 estimation		
Actual mean	21.49	21.14
Predicted mean	22.31	22.37
Difference	-0.81	-1.23
No. of values in a 10 percent range (in %)	79.43	64.98
Sultana et al. 2015 estimation		
Actual mean	2149	21.14
Predicted mean	21.06	21.16
Difference	0.43	-0.02
No. of values in a 10 percent range (in %)	73.20	74.36
Powell-Tuck and Hennessy 2003 estimation		
Actual mean	21.49	21.14
Predicted mean	21.16	21.23
Difference	0.34	-0.09
No. of values in a 10 percent range (in %)	88.02	88.40
Powell-Tuck and Hennessy 2003 estimation (age corrected)		
Actual mean	21.49	21.14
Predicted mean	20.00	20.06
Difference	1.51	1.08
No. of values in a 10 percent range (in %)	56.58	72.78

Table 13: Mean values of anthropometric measurements for selected years

	n	Height	Chest circ.	Upper arm circ.	Weight	BMI
1939						
< 19	1204	172.4	89.2	26.1	61.9	20.8
19-20	2046	171.7	88.8	26.1	62.4	21.2
20-21	233	173.7	86.4	25.3	60.2	20.0
>= 21	72	174.1	86.6	25.1	60.6	20.0
1929						
< 19	58	173.5	90.6	26.6		
19-20	1367	170.5	88.7	25.9		
20-21	798	170.5	88.9	26.0		
>= 21	184	171.6	87.3	25.3		
1928						
< 19	67	172.0	88.5	26.1		
19-20	1072	170.4	87.8	25.6		
20-21	1039	170.5	87.9	25.5		
>= 21	173	171.9	86.9	25.1		
1927						
< 19	48	171.9	88.2	25.5		
19-20	841	170.4	87.5	25.4		
20-21	1126	170.1	87.9	25.4		
>= 21	156	171.2	86.5	25.0		
1926						
< 19	36	169.3	88.7	26.2		
19-20	617	170.7	88.3	26.4		
20-21	1205	169.9	88.5	26.4		
>= 21	210	172.0	87.1	25.9		

Table 14: Estimated regression equation corrected for ages (training dataset 1933-1938)

	Weight estimation			
	Estimates	SE	t value	p value
Intercept	-102.3	1.36	-75.0	< 0.0001
Chest circ.	0.5	0.03	33.8	< 0.0001
Upper arm circ.	1.8	0.01	55.8	< 0.0001
Height	0.4	0.01	56.1	< 0.0001
Age 19-20	-0.2	0.25	-0.6	0.5400
Age 20-21	-0.7	0.29	-2.6	0.0107
Age >= 21	-0.6	0.34	-1.7	0.0840
adj. R2	0.78			

	Estimates	SE	t value	p value
Intercept	-102.5	1.32	-77.4	< 0.0001
Chest circ.	0.5	0.01	34.4	< 0.0001
Upper arm circ.	1.8	0.03	55.8	< 0.0001
Height	0.4	0.01	56.0	< 0.0001
adj. R2	0.78			

	BMI estimation			
	Estimates	SE	t value	p value
Intercept	8.1	0.45	17.6	< 0.0001
Chest circ.	0.2	0.00	34.2	< 0.0001
Upper arm circ.	0.6	0.01	56.4	< 0.0001
Height	-0.1	0.00	-37.6	< 0.0001
Age 19-20	0.0	0.08	-0.4	0.7068
Age 20-21	-0.2	0.10	-2.2	0.0302
Age >= 21	-1.0	0.12	-1.2	0.2442
adj. R2	0.68			

	Estimates	SE	t value	p value
Intercept	8.0	0.44	18.1	< 0.0001
Chest circ.	0.2	0.00	34.7	< 0.0001
Upper arm circ.	0.6	0.01	56.5	< 0.0001
Height	-0.1	0.00	-38.3	< 0.0001
adj. R2	0.68			

Table 15: World War II equation estimation accuracy weight (kg) and BMI (kg/m2)

	World War II dataset
Weight = Intercept + Chest + Arm + Height (WCAH)	
Actual mean	62.04
Predicted mean	62.72
Difference	-0.69
No. of values in a 10 percent range (in %)	93.62
BMI = Intercept + Chest + Arm + Height (BMICAH)	
Actual mean	20.78
Predicted mean	21.08
Difference	-0.29
No. of values in a 10 percent range (in %)	93.17

Figure 7: Weight and BMI estimation for two age groups
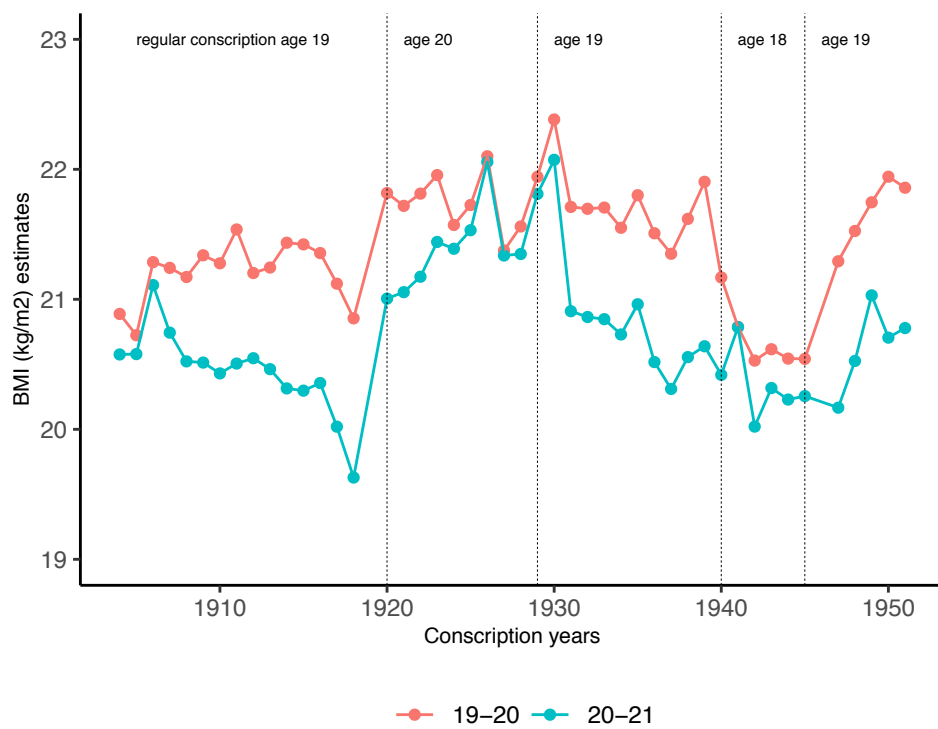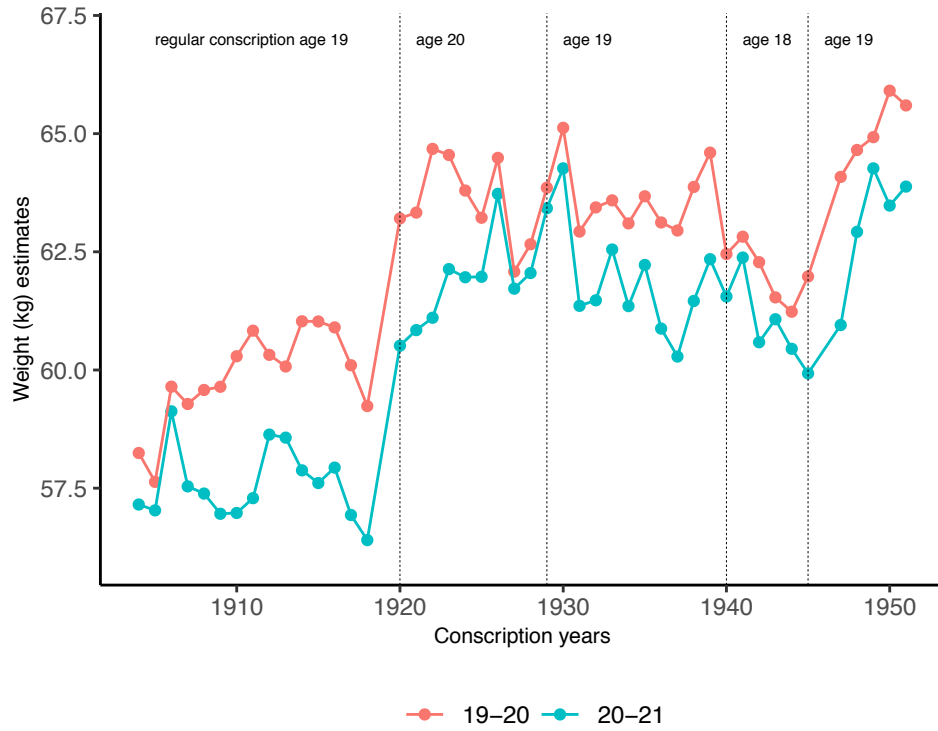
Figure 8: Scatterplot measured and estimated weight, test dataset 1933-1938 (WCAH equation)
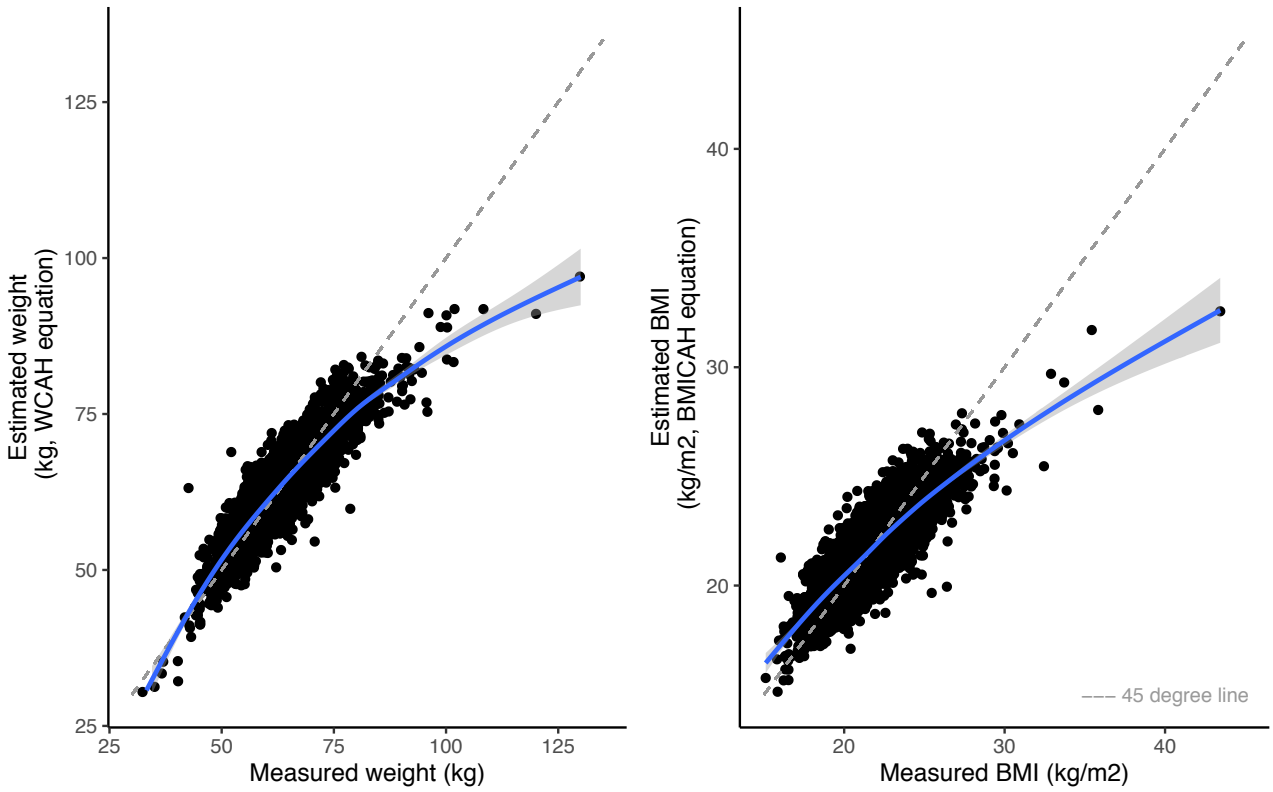

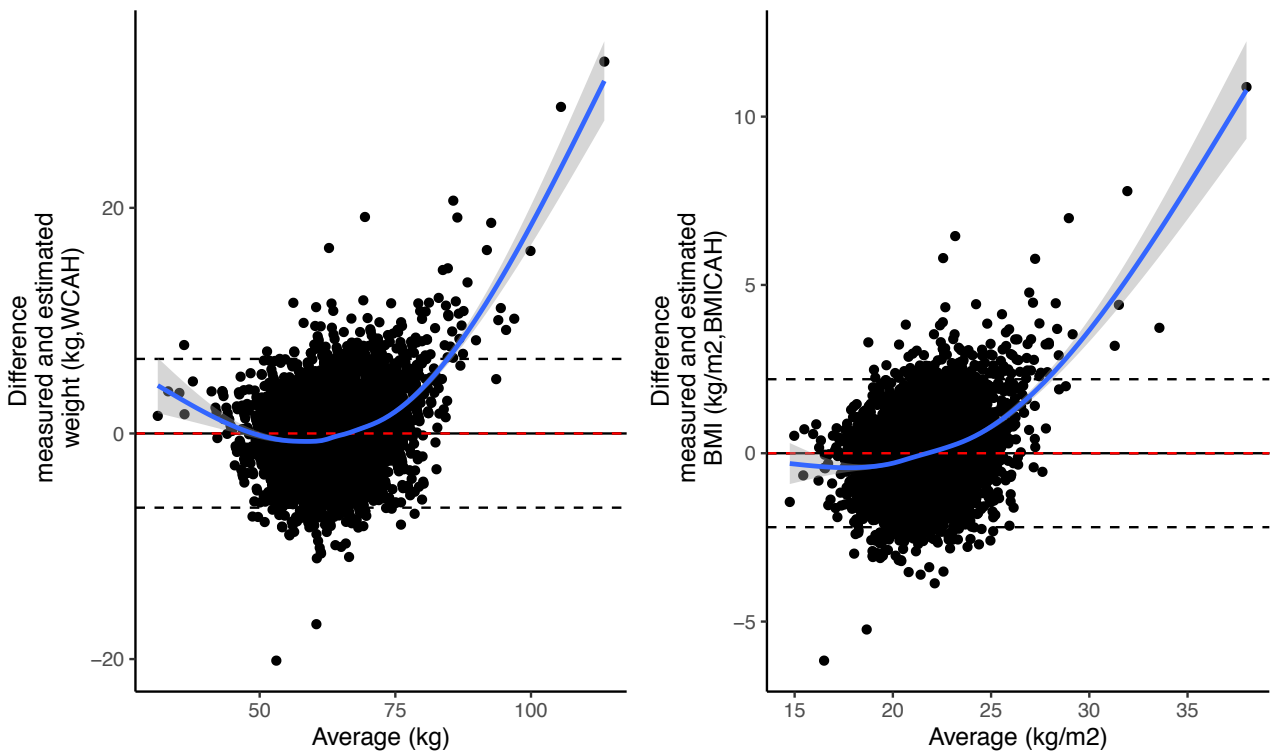**Figure 9: Weight and BMI Bland-Altman Plot, test dataset 1933-1938**

Figure 10: Density plots weight and BMI and estimated weight and BMI values 1933-1938 (test dataset)
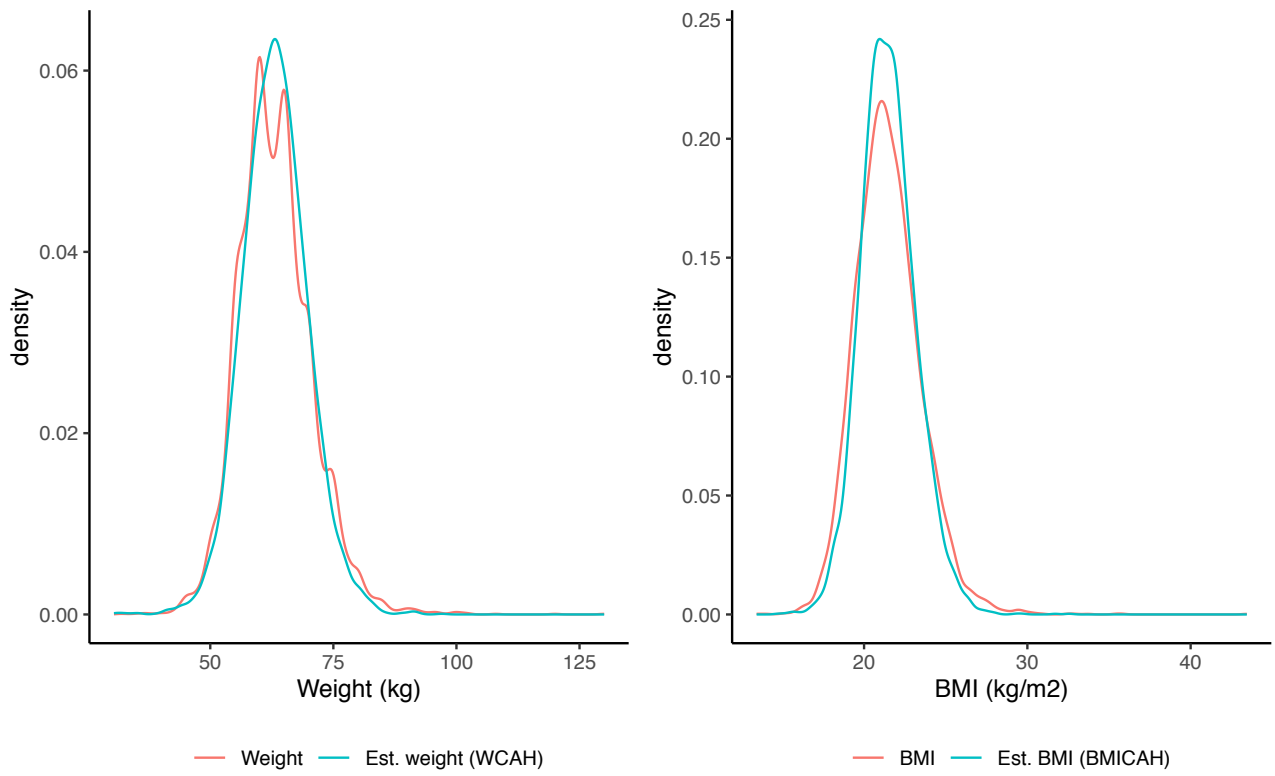
Figure 11: Histograms and kernel density estimation for height, chest circumference, mid upper arm circumference, weight and BMI 1933