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## **Size, body condition and adult mortality in rural Gambia: a life history perspective**

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### **Abstract**

Relationships between anthropometric status and mortality are of interest to a number of disciplines, including demography, nutrition and evolutionary biology. Here, an analysis of the relationships between three anthropometric measures and adult mortality is performed on data from a rural African population, and set within the framework of evolutionary life history theory. The results show clear associations between all three measures (height, BMI and haemoglobin level) and mortality for women, though the shape of these relationships is somewhat different between the three measures. For men, mortality is associated with BMI and haemoglobin level, but not height.

**Classification Code:** I12 - Health Production: Nutrition, Mortality, Morbidity, Substance Abuse and Addiction, Disability, and Economic Behavior

**Key words:** height, BMI, haemoglobin, adult mortality, life history theory

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## **Introduction**

Life history theory is a branch of evolutionary biology which considers the allocation of energy over the life course (Roff, 1992; Stearns, 1992; Stearns, 2000). Its core assumption is that organisms will use the energy they acquire in the service of reproductive success. Since energy used for one purpose cannot be used for another (the 'principal of allocation'), much of life history theory is concerned with energetic trade-offs. How do organisms solve the problem of allocating energy optimally between growth, physiological maintenance and reproduction? The study of demography is a key constituent of life history analysis: demographic patterns are both a constraint on, and a response to, life history events. For example, a important component of life history theory is the study of mortality schedules (Promislow and Harvey, 1991). This is partly because survival is essential to reproductive success, and therefore organisms must devote considerable effort to staying alive long enough to reproduce. But also because many causes of mortality are extrinsic to the organism, so that mortality schedules are a important constraint on life history strategies and will help determine how an organism allocates energy between growth, maintenance and reproduction (Hill and Hurtado, 1996, p179).

Our own species should be a prime candidate for life history research. Not only is there a large literature in the social and medical sciences on the demography, nutrition and physiology of humans, but the human species is also unusual in its ecological range. Many of the life history studies in the non-human literature are comparative studies, explaining life history variation between species with reference to each species' ecological environment (e.g. Harvey and Cluttonbrock, 1985; Wilkinson and South, 2002). With humans we can investigate life history variation (and similarities) across a range of environments for the same species. The aim of this paper is to add to the sparse but growing

life history literature for humans by investigating adult mortality in a subsistence agriculture community in Africa, with particular reference to the relationship between mortality and anthropometric measures (see Hill, 1993; Hill and Kaplan, 1999; Mace, 2000 for reviews of life history theory applied to human populations; Hill and Hurtado, 1996 for the most comprehensive example).

Two issues will be examined. Firstly, the relationship between size (in this case defined as height) and adult mortality will be determined. Body size has received much attention in life history analysis (see Roff, 1992, Chapter 7; Stearns, 1992, Chapter 6). Between species, body size correlates with a number of life history traits, including mortality rates. Large species tend to have lower mortality rates and longer lifespans (Harvey and Zammuto, 1985; Gaillard *et al.*, 1989). Humans are no exception to this rule. As a large bodied mammal, we have relatively low mortality and long lives (though our lifespan is even longer than would be predicted by our body size: Hill and Kaplan, 1999; Hill *et al.*, 2001). Within species the relationship between size and mortality is less clear-cut. Large size confers some benefits, such as protection from predators, but there are also costs to large size, for example, the greater nutrient requirements of maintaining large body size (Blanckenhorn, 2000). Laboratory studies on rodents have suggested that severe caloric restriction retards growth (resulting in a small bodied adult) but also lengthens lifespan, which suggests that fast growth may have negative impacts on subsequent mortality and lifespan (Rollo, 2002; Metcalfe and Monaghan, 2003).

The relationship between adult size (height) and mortality in our own species is already well studied. Secular changes in height have been shown to be correlated with mortality trends in both the US and the UK: as the average height of the population increases, so does

life expectancy (Floud *et al.*, 1990; Fogel, 1993). Within populations, tall height has also been correlated with lower mortality rate (Marmot *et al.*, 1984; Waaler, 1984). However, the situation is not entirely straightforward. Cause-specific analysis of mortality suggests that though the incidence of some causes of death, such as cardio-vascular and respiratory disease, are inversely related to height; others, such as reproductive cancers, increase in frequency with height (Barker *et al.*, 1990; Leon *et al.*, 1995; Smith *et al.*, 2000; Song *et al.*, 2003). This has led to a questioning of the prevalent view that tall height is beneficial (Samaras *et al.*, 2003). A drawback of this research is that much of it has been carried out in Western populations, where adequate nutrition and medical care are widely available. Less is known about the effect of height on mortality in the type of population which would have characterised most of human history, where food is in short supply and the important causes of death are acute, rather than chronic, diseases. Here, the relationship between adult height and all-cause mortality is investigated in a poorly nourished society without access to medical care.

The second goal of the paper is to analyse the relationship between current body condition and adult mortality. Adult height reflects a combination of an individual's genetic potential and past life history experiences. An understanding of how adult mortality varies by *current* body condition is also valuable for life history studies. Life history theory would predict a negative correlation between body condition and mortality rates, but there are still questions to be resolved. For example, which measures of body condition are the best predictors of mortality? Given that life history theory is concerned with the allocation of energy, a measure of nutritional status will clearly be a good candidate. A measure such as body mass index (BMI: which measures weight for height) should be a good indicator of chronic energy deficiency (or excess: Bailey and Ferro-Luzzi, 1995). However, nutrition is not the

only factor affecting energy balance. Also important are the demands being made on these nutritional reserves. An important component of body maintenance is the ability to fight off disease. While this may be partly genetically determined, immune defence is energetically expensive. There is a well-known synergy between malnutrition and infectious disease, with malnutrition exacerbating infection and vice versa (Beisel, 1982; Scrimshaw, 2003). Measures of immunological competence are widely used in the animal literature as an indicator of body condition, and have been correlated with a number of life history parameters (Sheldon and Verhulst, 1996; Lochmiller and Deerenberg, 2000; Norris and Evans, 2000; McDade, 2004). Here, haemoglobin level (a marker of anaemia) is used as a convenient indicator that should reflect both nutritional status and disease load (Wadsworth, 1992; Stephenson, 1993; Gilgen and Mascie-Taylor, 2001), and may therefore be a more sensitive indicator of body condition than BMI alone.

Another question to be resolved is the shape of the relationship between measures of body condition and mortality. As with height, much research has already been done on the relationship between BMI and mortality. A non-linear relationship is usually found (Wienpahl *et al.*, 1990; Rissanen *et al.*, 1991; Laara and Rantakallio, 1996; Yuan *et al.*, 1998; Engeland *et al.*, 2003; Kuriyama *et al.*, 2004). Individuals with low BMI suffer high mortality rates, but so do those with high BMI. Again, most of this research is carried out in well- (if not over-) nourished societies, but one recent study that did investigate the relationship between BMI and mortality in a food stressed Bangladeshi population found a similar non-linear relationship to that seen in the West (Hosegood and Campbell, 2003). Women in the lowest and highest quartiles of BMI suffered higher mortality rates than those of intermediate weight, though the consequences of low BMI were more serious than those of high BMI. This is notable because women in the highest quartile of BMI were well

within the range considered to be of appropriate weight by internal standards (this quartile included women with a BMI >19.61; a BMI of >25 is needed before an individual is considered to be overweight). This raises the possibility that the relationship between body condition and mortality may depend on relative, rather than absolute, body condition.

Similar studies of the effects of anaemia on adult mortality are relatively rare, although there is considerable research on anaemia in reproductive-aged (and particularly, pregnant) women (*e.g.* Isah *et al.*, 1985; Tracer, 1997; Allen, 2000; Bentley and Griffiths, 2003).

Anaemia is known to be associated with maternal mortality (Thonneau *et al.*, 1992; McDermott *et al.*, 1996; MacLeod and Rhode, 1998; Walraven *et al.*, 2000; Brabin *et al.*, 2001), and has also been correlated with higher non-maternal mortality rates for reproductive-aged women (McDermott *et al.*, 1996), and with higher mortality of older individuals of both sexes (Izaks *et al.*, 1999). For maternal mortality at least, this relationship may not be linear, as some studies report only an effect of severe, rather than mild or moderate, anaemia (Rush, 2000; Brabin *et al.*, 2001).

Finally, the relationship between condition and mortality will be examined separately in both women and men to determine whether there are any significant sex differences. Potential differences between the sexes may be enhanced in the high fertility population studied here, where women have to bear the energetically expensive demands of pregnancy and lactation repeatedly during their reproductive lives. Previous research on whether the BMI-mortality relationship is the same in men and women is inconsistent. Some studies find a similar relationship between BMI and mortality for both sexes (Engeland *et al.*, 2003); others find that the shape of the relationship differs between the sexes, but these results do not show any consistent pattern (Wienpahl *et al.*, 1990; Dorn *et al.*, 1997;

Kuriyama *et al.*, 2004). There may also be differences between the sexes in the relationship between anaemia and mortality. Levels of anaemia vary considerably between the sexes (*e.g.* Kent, 1992), and anaemia appears to be a particularly important risk factor for maternal mortality, which will not affect men.

## **Data**

The data were collected from four villages in rural Gambia under the auspices of the UK Medical Research Council (MRC: see McGregor, 1991 for a full description of the study)<sup>1</sup>. A demographic surveillance system has been in place in these villages since 1950, recording all births and deaths. Anthropometric data was systematically collected at least annually from all available villagers between 1950 and 1980. In 1975 a permanently staffed research station was set up in the largest village, which included a medical centre that provided free treatment to villagers. This analysis is confined to the period between 1950 and 1974, as the medical clinic resulted in a rapid decline in mortality rates (Lamb *et al.*, 1984; Weaver and Beckerleg, 1993; Sear, 2001). Between 1950 and 1974, these villages had little access to medical care, though the primary researcher (Ian McGregor, a medical doctor) did provide medical treatment to individuals as necessary during his visits to the area.

The population largely supported itself with subsistence agriculture between 1950-74, though some income was earned through the sale of groundnuts. This West African environment is very seasonal. During the rainy season, heavy workload, low food supplies and high disease transmission (particularly malaria) coincided, which adversely affected the health of villagers: adults routinely lost weight during the rainy season (McGregor, 1976).

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<sup>1</sup> Thanks to the Gambian Scientific Co-ordinating Committee and Ethical Committee for permission to use the data

Before the advent of the medical clinic, both birth and death rates were high: women had around 7 children on average, but almost half died before the age of 5 years (Billewicz and McGregor, 1981).

The growth of children in these villages has already been comprehensively documented (McGregor *et al.*, 1961; McGregor *et al.*, 1968; Billewicz and McGregor, 1982). Children grew well relative to international standards initially, but growth-faltering began around the age of three months and growth thereafter lagged significantly behind that of Western children. Growth was strongly affected by season. Children grew much more slowly during the rainy season than the dry. The Gambian children had an extended growth period compared to Western counterparts, but this was not sufficient to make up for their slower growth, so that adults in this population were relatively short and light. Anaemia was common and severe in childhood, and followed a similar seasonal pattern to that of nutritional status (McGregor *et al.*, 1966). Malaria levels were also high during the rainy season, and haemoglobin levels were correlated with the presence of malaria parasites in the blood.

Between 1950 and 1980, approximately 22,700 anthropometric measurements were taken from about 1,900 adults in these villages (throughout this paper an 'adult' is defined as an individual 21 years or older, as growth had ended in virtually all individuals of both sexes by this age: Roberts *et al.*, 1978). Rather more measurements were taken from women than men: about 9,500 measurements were taken from 900 men, and 13,200 measurements from 1,100 women. The majority of measurements were taken during the dry season, as villagers were heavily involved in agricultural work during the rainy season. Table 1 summarises the anthropometry of adults in these villages. Heights and weights were

recorded in inches and pounds respectively and converted to centimetres and kilograms for this analysis. BMI ( $\text{kg}/\text{m}^2$ ) was then calculated from these converted measurements. Figure 1 shows the relationships between each measure of anthropometric status and age for both sexes. All measures are clearly related to age, though the nature of these relationships is somewhat different between the sexes. Height declines among older adults of both sexes, as does BMI. Haemoglobin levels tend to decrease with age in men, but broadly increase with age in women.

## **Methods**

The probability of dying in adulthood (*i.e.* from the age of 21 years) was analysed between 1950 and 1974 using discrete-time event history analysis (EHA). EHA models the probability of an event, in this case a death, happening over time. Such models have the two advantages of being able to deal with censored data, and can include time-varying covariates (Allison, 1984). Individuals were both right-censored (those without a known date of death were right-censored at the age they were last known to be alive, and all individuals still alive were censored in 1975) and left-censored (those who reached the age of 21 before 1950 were only included in the analysis from the age they had reached in 1950). Separate models were run for women and men.

Height, BMI and haemoglobin were entered simultaneously into each model to test for their effects on the probability of death in adulthood. Non-linear effects of all measures of anthropometric status were tested for by including quadratic terms, and by calculating quartiles of each anthropometric measure and including dummy variables for three of the four quartiles. The models also controlled for birth cohort.

BMI and haemoglobin were included in the models as time-varying covariates. Few individuals were surveyed in every year between 1950 and 1980, so a mean BMI or haemoglobin measurement was calculated for each individual for 5-year age blocks (for the ages 21-24, 25-29, 30-34 *etc*, up to the age groups 70-74, 75 and over), assuming the individual had more than one measurement in the 5-year age block. These mean BMI and haemoglobin measurements were then entered into the model as time-varying in 5-year age blocks. If no measurements were taken in a particular age block, the mean of the 2 measurements in the immediately younger and older age blocks was calculated and included in the model for the age block with missing data. All measurements taken within 12 months of death were excluded when calculating these 5-year means, to avoid a decline in body condition prior to death contaminating the results. For women, BMI and haemoglobin measurements taken during pregnancy were also excluded, as were measurements taken within three months after a birth for the haemoglobin analysis (haemoglobin declines during pregnancy and takes a few months after birth to return to pre-pregnancy levels).

Height is clearly less variable with age than either BMI or haemoglobin, though does show a decline in older adults. Height was therefore included as time-constant until the age of 49 years, and time-varying for older individuals. A mean height was calculated for each individual using all measurements collected between the ages of 21 and 49, and this measurement was included as the individual's height for ages under 50 years. From the age of 50 onwards, height was included as a time-varying covariate. These time-varying height measures were constructed using the same method as for BMI and haemoglobin.

## Results

### *Anthropometric status*

Adults in these villages were in relatively poor nutritional condition relative to Western populations (Table 1). They were comparatively short: the average man was around 168cm, the average women 158cm. These villagers were also relatively light, though the majority were within the weight range considered adequate by international standards. Mean BMI for both men and women was approximately 20. A minority of measurements are considered underweight by international standards, but only a tiny fraction are considered overweight. If an average BMI is calculated for each individual then 148 (12.9%) women and 122 men (13.4%) were underweight, but only 8 men (0.9%) and 33 women (2.9%) were overweight (BMI>25). None were obese, with a BMI of 30 or over (no man ever recorded a BMI of 30 or more, and only 0.2% of BMI measurements from women were greater than 30). This population did suffer from considerable iron deficiency, however. The average woman in this population was anaemic: around half of all haemoglobin measurements from women were below the cut-off for anaemia (<12 g/dl). Men were slightly better off in that the average man was not anaemic, but one-third of measurements from men were also considered anaemic (<13 g/dl).

### *Mortality*

Individuals in this population who survive to adulthood can expect to live into their late 60s: median age at death for women who survive to at least 21 years is 68, median age at death for men is 67. Mortality rates in adulthood are similar for women and men (Figure 2). Female mortality is a little higher during the reproductive years; male mortality is a little higher in older adulthood. Overall, there is no significant difference in the survival distributions of the sexes (log rank statistic = 0.31, df=1, p=0.57).

### *Mortality and anthropometric status*

The results of the event history analyses demonstrate a clear relationship between body condition and mortality for both sexes, but the nature of these relationships differs between different measures of body condition, and between men and women (Table 2). Height shows the greatest differences between the sexes. For women there is a significant relationship between height and the risk of death, though this relationship is not linear. Figure 3(a) plots the model predictions of the probability of death for a 30-year old woman across the range of heights seen in the population (excluding extreme values). The lowest mortality is seen for women of approximately average height; both short and tall women suffer relatively high mortality risks. For men there is no evidence that height and mortality are correlated, as neither linear nor non-linear functions of height are significantly related to mortality risk.

For BMI and haemoglobin, the relationship between anthropometric status and mortality is very similar for both sexes. BMI also shows a non-linear relationship with mortality. Figure 3(b) shows the model predictions of the effects of BMI on mortality for both men and women. Across most of the observed range of BMI, increasing BMI decreases mortality risk, but at high BMI mortality risks level off and then begin to rise. haemoglobin shows a linear correlation with mortality for both women and men (Figure 3(c)). The risk of death decreases as haemoglobin increases across the range of observed haemoglobin levels.

The relationships between different anthropometric measures and mortality appear to be independent of one another. Preliminary models were run where only a single anthropometric measure was included in the model. The results of these models were very

similar to the results of the final, multivariate model. Interaction terms between the anthropometric measures were included in preliminary models, but were not significant. Interaction terms between each anthropometric measure and age were also included in preliminary models but were not significant, suggesting that the relationship between anthropometric status and mortality does not vary by age.

## **Discussion**

Size (height) is related to mortality in this population for women but not for men, though this relationship is not linear. The higher mortality of short women may be partly explained by maternal mortality. Short stature increases the risk of prolonged and difficult labour, primarily due to cephalopelvic disproportion (Sokal *et al.*, 1991; Tsu, 1992; Moller and Lindmark, 1997), which is likely to result in high maternal mortality rates for short women in settings where modern medical care is unavailable. Though the numbers are too small to permit meaningful statistical analysis, the mean height of the 10 women known to have died from maternal causes before 1975 is 155.8cm, which is 2cm shorter than the mean height for the entire female population (157.8cm).

Short height is also an indicator of conditions an individual experienced during childhood, such as nutritional availability and prevalence of disease. If there is a link between poor conditions in childhood and poor conditions in adulthood (mediated, for example, by socio-economic status), then this may explain the correlation between short stature and high mortality. It has also been suggested that an adverse environment in early life (particularly during the foetal period) results in a higher incidence of disease in later life (Barker, 1994). Adverse early life conditions may result in both short adult height and high adult mortality rates, thus mediating the link between adult and mortality. Most of this research has

focused on chronic diseases in Western populations, but an analysis of the effects of season of birth on adult mortality in this Gambian population suggests a similar association with infectious disease (Moore *et al.*, 1997; Moore *et al.*, 1999; but see Moore *et al.*, 2004). Individuals born during the ‘hungry’ season (when food was scarce and disease rife) have higher mortality in adulthood than those born during the ‘harvest’ season (when food was more plentiful and disease less so). This study included data collected after 1975. It was not possible to determine relationships between season of birth, height and adult mortality in the sample used here. Season of birth was known for few individuals in this sample, as most were born before 1950 when demographic surveillance began.

The increased mortality of taller women is harder to explain. Though studies in Western populations have shown increased mortality from certain cancers in taller individuals, cancer was probably a relatively minor cause of death among these Gambian women (though little information on cause of death is available during this time period, with the exception of some information on maternal deaths). In addition, ‘tall’ Gambian women were not particularly tall by Western standards. The tallest woman was around 178cm (5’10), and 95% of women were 167cm or less (approx 5’6). A potential cost to relatively tall height that could apply to this population is suggested by the life history literature: taller individuals need relatively large amounts of energy to maintain their somatic tissue. There is considerable seasonal and also yearly variation in food availability and disease prevalence in this part of the world. Tall individuals may suffer more than shorter individuals during lean periods because of their greater energy requirements. However, this logic should apply to both men and women, yet the analysis suggests the correlation between height and mortality applies only to women. An alternative hypothesis is that the higher mortality of tall women could be linked to reproduction. The advantages of large

size are thought to include more successful reproduction, and it has been shown previously in this population that taller women are more reproductively successful than shorter women (Sear *et al.*, 2004). In particular, the survival of the children of tall women is markedly higher than that of the children of shorter women. Successfully raising many children to adulthood may create additional energetic stresses on taller women which ultimately lead to higher mortality rates.

The relationships between BMI and mortality, and haemoglobin and mortality for both sexes are rather more straightforward. This analysis suggests that mortality rates decrease as both BMI and haemoglobin increase, as would be predicted by life history theory: individuals with access to greater energetic reserves use them to lower their mortality rates. The model suggests that relatively high BMI does lead to higher mortality rates, but that the consequences of low BMI are much more severe than those of high BMI. The increase in mortality among overweight individuals is relatively slight (Fig. 3b), and overweight individuals in any case are rare in this population. It is perhaps surprising that the relationship between BMI and mortality is so similar between the sexes, given that women have to bear the energetic costs of regular pregnancies and lactation. But recent research by both nutritionists and evolutionary biologists has suggested that women do have a number of adaptations which allow them to mitigate the costs of reproduction (*e.g.* Peacock, 1991; Ellison, 1994; Dufour and Sauter, 2002; Ellison, 2003). Women appear to delay reproduction until they are in suitable condition to bear such a high energetic cost, for example. Such adaptations can be seen in the Gambian population reported on here: women with low BMI (and haemoglobin levels) have slower birth rates than those in better condition (Sear *et al.*, 2003), and only those in relatively good condition are able to produce twins (Sear *et al.*, 2001). Research by the MRC in this population after 1975, has also

demonstrated that women are able to make metabolic adjustments which minimise the energetic stresses of pregnancy (Prentice and Whitehead, 1987; Poppitt *et al.*, 1993; Prentice and Goldberg, 2000).

There seem to be no diminishing returns to increasing haemoglobin in terms of mortality rates, as there was no evidence for a non-linear relationship between haemoglobin and mortality. This relationship is similar for both sexes, though the models indicate that the mortality costs of severe anaemia are greater for women than for men. This could be related to maternal mortality, as severe anaemia greatly increases the risk of maternal mortality, though mild or moderate anaemia does not appear to have the same effect (Rush, 2000; Brabin *et al.*, 2001).

### *Conclusion*

To answer the questions posed in the Introduction, there is clear evidence that current body condition has a significant impact on adult mortality rates for both sexes. Both nutritional status (BMI) and haemoglobin level (an anthropometric measure which is affected by disease load) were independently related to mortality risk, suggesting that both are good indicators of current body condition. The relationship between measures of body condition and mortality is essentially linear: as body condition increases, the probability of death decreases. Though there do seem to be some costs to energy acquisition among those individuals who acquired sufficient energy to become overweight, this accounts for a very small proportion of the population. The condition-mortality relationship is similar for both sexes, despite some differences in condition between the sexes (for haemoglobin but not BMI), and differences in the association between these anthropometric measures and age.

Ecology also seems to matter for the relationship between size and mortality, though perhaps less so for the relationship between current body condition and mortality. The reverse J-shaped correlation between BMI and mortality, for example, appears to be the common pattern across both well nourished and poorly nourished populations (in relative, if not absolute, terms). The size-mortality relationship is more complicated. Broadly speaking, the all-cause mortality for men in Western populations decreases with increasing height. This may not be the case in populations with lower nutrient intakes, since no relationship between height and mortality was found for men in this study or in a nineteenth century population (Murray, 1997). Relationships between height and mortality for women appear more variable. The U-shaped relationship observed here has been found in Western populations (Laara and Rantakallio, 1996; Engeland *et al.*, 2003), but so has a linear decrease in mortality with height (Jousilahti *et al.*, 2000; Smith *et al.*, 2000). Additionally, the study of Bangladeshi women reported earlier found no effect of height on mortality (Hosegood and Campbell, 2003). As discussed in the Introduction, large size brings both costs and benefits, and these may differ between environments. It is also affected by previous life history experiences, which may include not only conditions encountered during early life but also life history events such as age at first birth. Growth and reproduction are both energetically costly, so a trade-off between height and age at first birth is often found. As seen in this Gambian population, tall women tend to have later first births than shorter women (Allal *et al.*, 2004). Complex relationships between energy availability, growth, reproductive events and height may make it difficult to draw general conclusions about the relationship between height and mortality. More research on this relationship for both sexes across a range of societies is needed to determine if any consistent patterns emerge, and whether these have any functional significance.

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**Table 1: Summary of adult anthropometric data**

	<b>Women</b>	<b>Men</b>
<b>Height (cm)</b>		
Number of measurements	13,160	9,559
Mean $\pm$ SD	157.8 $\pm$ 5.6	168.0 $\pm$ 6.7
Range	122.5-178.4	127.6-196.8
<b>BMI (kg/m<sup>2</sup>)</b>		
Number of measurements	11,479	9,553
Mean $\pm$ SD	20.7 $\pm$ 2.3	20.4 $\pm$ 1.8
Range	12.3-39.7	13.5-29.9
% Underweight (<18.5)	15.9	13.3
Mildly (17-18.49)	12.5	11.3
Moderately (16-16.9)	2.6	1.5
Severely (<16)	0.8	0.5
% Overweight (25+)	3.7	1.5
Obese (30+)	0.2	0
<b>Hb (g/dl)</b>		
Number of measurements	10,848	9,532
Mean $\pm$ SD	11.7 $\pm$ 1.7	13.5 $\pm$ 2.1
Range	2.0-17.1	2.7-20.0
% Anaemic (<12 for women, <13 for men)	48.3	33.1
Mildly (10-11.9/12.9)	35.7	26.6
Moderately (7-9.9)	12.0	5.5
Severely (<7)	0.6	0.9

**Table 2: results of event-history analysis on the probability of dying. Models also control for birth cohort**

Variable	Women		Men	
	Estimate	SE	Estimate	SE
Age	0.077	0.012**	0.065	0.012**
Height	-1.032	0.486*	0.008	0.013
Height squared	0.003	0.001*		
BMI	-0.722	0.285*	-0.9391	0.401*
BMI squared	0.015	0.007*	0.020	0.009*
Haemoglobin	-0.300	0.050**	-0.192	0.037**
Number of deaths		162		156
Number of survivors		836		671

\* p<0.05, \*\* p<0.001

## Figure legends

Figure 1: mean height (a), BMI (b) and haemoglobin (c) by age group  $\pm$  95% confidence intervals. Solid line represents women, dotted line men.

Figure 2: Kaplan-Meier plot showing survival function of women (solid line) and men (dotted line) who survived to at least 21 years. N=1125 women, of whom 208 died; N=968 men, of whom 201 died.

Figure 3: Model predictions of probability of dying by height (a), BMI (b) and haemoglobin (c). Solid line represents women, dotted line men.

Figure 1 (a)

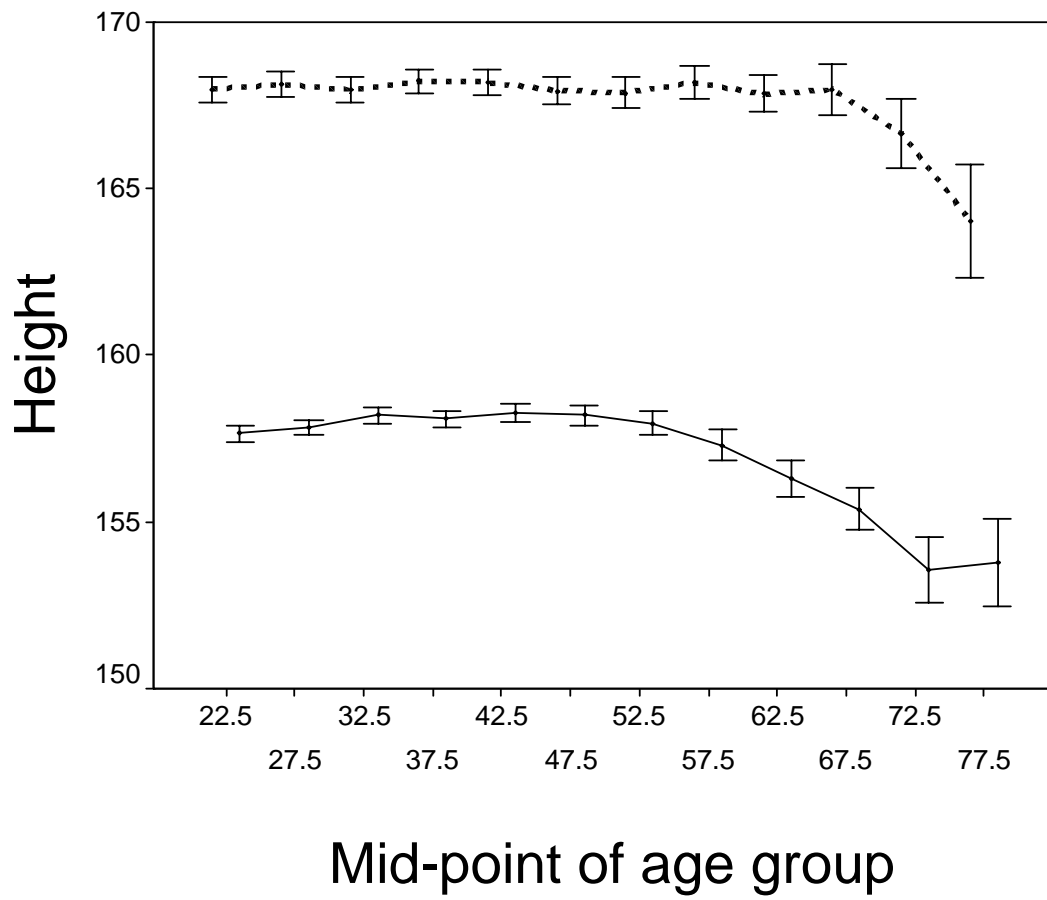


Figure 1 (b)

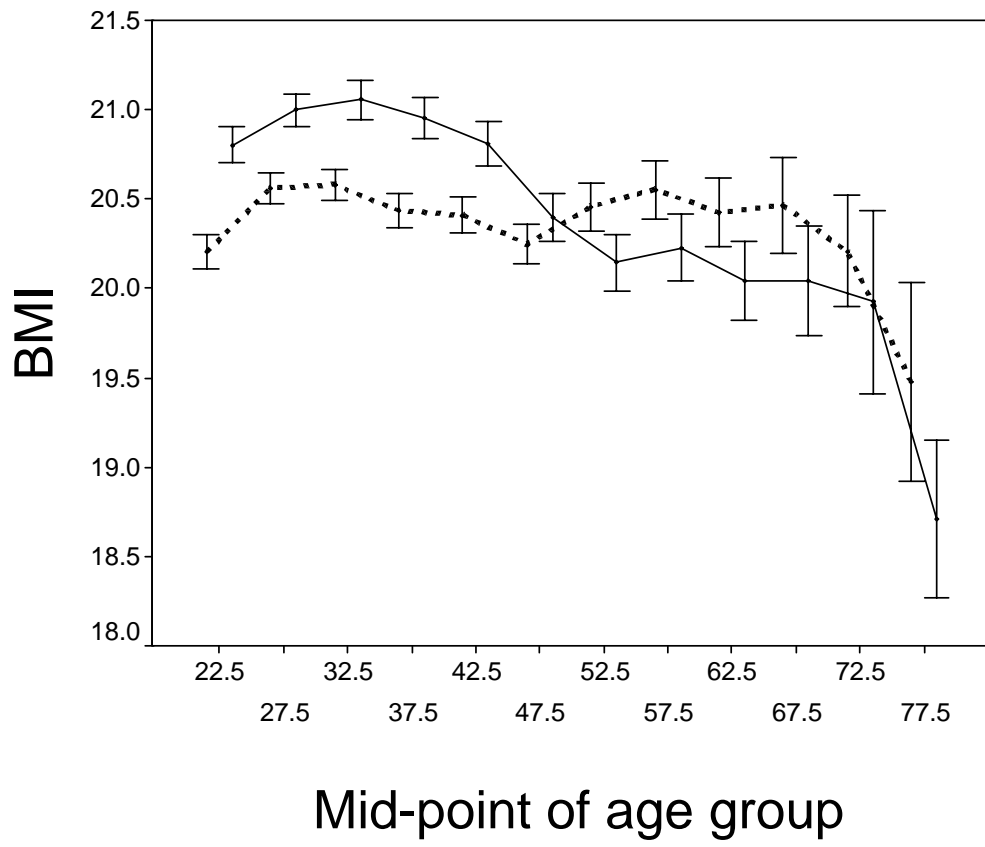


Figure 1 (c)

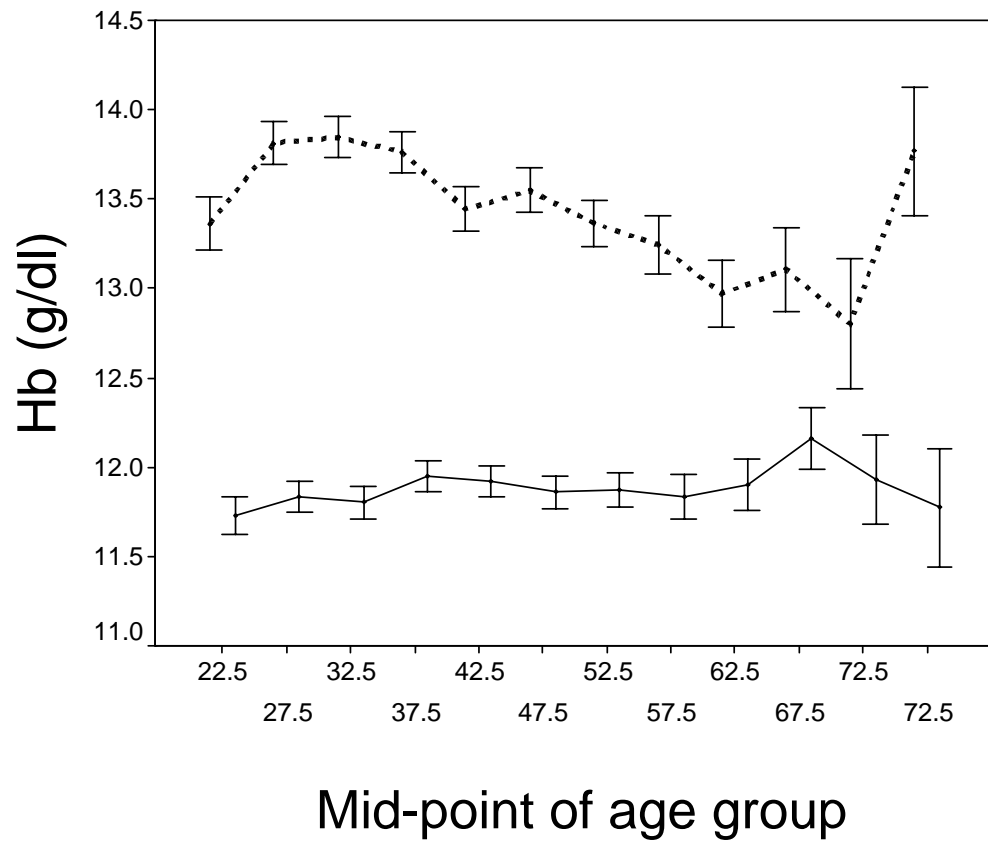
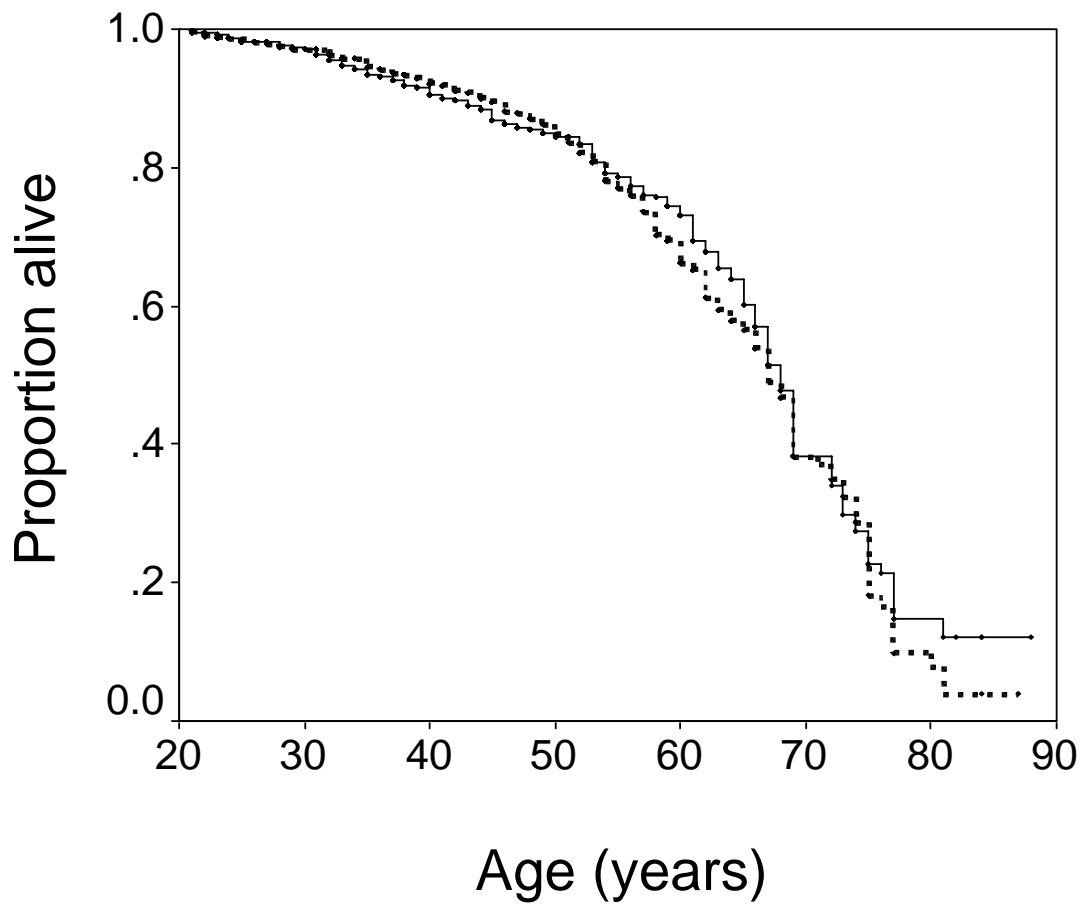


Figure 2



**Figure 3 (a)**

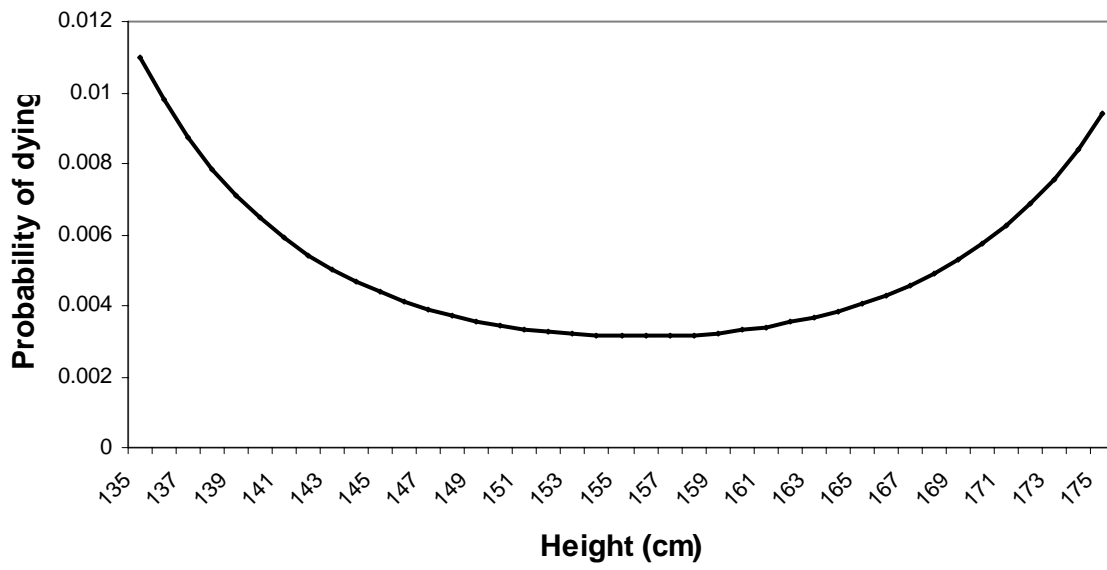
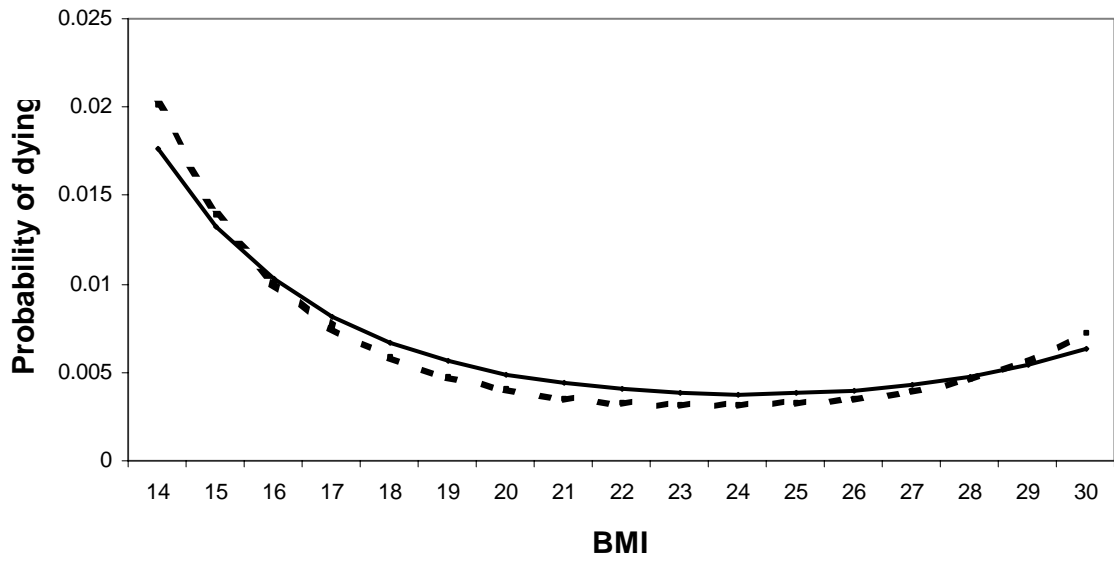


Figure 3 (b)



**Figure 3 (c)**

