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Weight Changes in Adult Twins

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Longitudinal study of 514 pairs of US white male twin veterans was made possible by compiling data from military records, mailed questionnaires, and physical examinations. Height and weight were used to calculate the Quetelet index for twins at different ages covering induction into the Armed Forces (generally 17–24 years), 25 years, 40–50 years at questionnaire response, and 42–56 at physical examination. Cross-sectional analyses of Quetelet Index at these 4 points in time showed consistent evidence of significant genetic variance. Additional twin analyses of change in Quetelet Index both from induction and from age 25 to approximately age 48 were done. Both analyses showed significant genetic variance for change in Quetelet Index during this time span of 25 or more years for most subjects. Heritability estimates were 0.6 for change in Quetelet Index from induction (mean age 20) to examination (mean age 48) and 0.7 for change in Quetelet Index from age 25 to examination. While studies of younger twins have shown significant genetic influence on growth (height and weight), this study of adults demonstrates significant genetic influence on change in weight even after maturation.

Key words: Weight, Quetelet Index, Heritability, Twins, Obesity

INTRODUCTION

The heritability of height, weight, and relative weight have been established by many studies on twins of all ages. Height and weight consistently show significant genetic variance, as does relative weight or obesity, whether it is measured with Metropolitan Relative Weight (weight as a percentage of ideal weight for a given height), skinfold measurements, or by some index relating weight and height such as the Ponderal Index or Quetelet Index.

Longitudinal studies of changes in height and weight in twins are less numerous. Most of these studies have been confined to young twins, generally under 20 years of age, and

The use of military medical records in this research is acknowledged, but it is not to be construed as implying official approval of the conclusions presented by the Departments that provided these records.

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they concentrate on the growth years [5, 6, 9, 10]. These studies generally show significantly higher intraclass correlations among monozygotic (MZ) than among dizygotic (DZ) twins for height and weight as well as for changes in these variables over time. This paper will examine the heritability of change in relative weight (Quetelet Index) for men from the time they reach maturation to middle age.

METHODS

The NHLBI Twin Study was conducted from 1969–1973 using a group of 1028 white male veteran twins aged 42–56. The twins were ascertained through the NAS-NRC Twin Registry which contains 15,924 male twin pairs born from 1917 to 1927 [7]. Twins were examined at five centers in the United States: Framingham, MA; Indianapolis, IN; and Davis, San Francisco and Los Angeles, CA. The examinations included a physical examination, laboratory analyses, and a series of questionnaires ranging from diet history and personal and family history to data on intra-twin pair relationships. Greater detail of the methods of this study have been published previously [3]. Zygosity was determined using data for 22 red blood cell antigens, dermatoglyphics, and the twins' opinions. The study group consisted of 250 MZ and 264 DZ pairs.

In addition to examination data, the NAS-NRC Twin Registry has accumulated data on its members who have been followed extensively since 1965. The twin panel itself was compiled by matching state birth records to Veterans Administration records. Data were then obtained from induction records gathered mostly during the period of World War II or occasionally, during the Korean conflict. In addition, data were available from mailed questionnaires that have been sent periodically since the registry came into existence in the mid 1960s. Most height and weight measurements so obtained are from 1967. The data for this paper will use height and weight information from induction records, mailed questionnaires; and physical examinations. These data span an adult age range of approximately 28 years. Values for height and weight were originally recorded in inches and pounds and were converted to centimeters and kilograms for this paper.

Induction data provided measurements of height and weight at induction which ranged from ages 15–28. In 1967 a mailed questionnaire elicited current height and weight data as well as weight at age 25. When this questionnaire was sent, the twins ranged in age from 40–50, requiring a recall to as much as 25 years earlier. Finally, height (to the nearest quarter inch) and weight (in pounds) were measured during the physical examinations that took place when the twins were aged 42–56 or 2–6 years after the mailed questionnaires were completed. Data were converted to metric units. Table 1 summarizes the data available for analysis at the various times in the twins' lives.

From these data the Quetelet Index (Q.I. = $1000 \times \text{weight(kg)}/\text{height}^2\text{(cm)}$) was calculated as a measure of obesity or relative weight. The higher the number the heavier the individual for his height. Q.I. was calculated at induction, at the time of the mailed questionnaire; and at examination using the respective weight and height values. In addition, Q.I. was calculated at age 25 and at the time of the mailed questionnaire using the corresponding weights but with the height measurement from the physical examination in 1969–1973. It was assumed that measured height from the examination offered the most accurate value for height after maturation and would be most appropriate for all

TABLE 1. Summary of Data Available for Longitudinal Analysis

	Height[a]	Weight[b]	Age	Method of obtaining data
Induction into armed forces	X	X	15–27	Measured
Age 25		X	25	Estimated 23 years later
Mailed questionnaire	X	X	40–50	Estimated at the time
Examination	X	X	42–56	Measured

[a]Originally recorded in inches, converted to cm.
[b]Originally recorded in pounds, converted to kg.

indices at age 25 and beyond. Comparisons of heights from the mailed questionnaire and examination provided evidence that the questionnaire responses tended to overestimate height. These data are described later in more detail.

Q.I. and change in Q.I. describing the relative weight characteristics of the twins were then analyzed using the twin analysis method of Christian et al [1, 2]. This method takes into account the possibility of unequal total variances for MZ and DZ twins and provides an unbiased estimate of genetic variance in this circumstance. In all but one instance the results reported in this paper are equivalent to results using classical twin analysis methods. Twin analyses and estimates of genetic variance will be summarized by the intraclass correlations and heritability estimates (using $h^2 = 2(r_{mz} - r_{dz})$).

RESULTS

Table 2 presents the mean weight by zygosity for each point in time that data are available. Mean weight increases 6–7 kg in the period from induction to age 25. The mean age at induction was 19.9 years, with a range of 15–28, but with 92% between ages 17–24. Thus, induction to age 25 represents approximately a 5-year interval, several years of which included military service. During this interval many of the twins were still growing as will be seen in Table 3, which is described in the next paragraph. Mean weight change from age 25 to the time of the questionnaire, essentially a time of constant height, was 6.4 kg for both MZ and DZ twins. Weight was little changed over the short interval from the time of the mailed questionnaire to the examination. It should be noted that the questionnaire weight is a subjective response while examination weight was measured.

Height shows greater variation from measurement to subjective response than weight as can be seen in Table 3 which presents height at each available point in time. Questionnaire height averages 2 cm higher than examination height which was 2–6 years later. It appears that twins tended to overestimate their height when questioned. Comparison of the distributions of examination height to questionnaire height indicated 1/3 of the twins reported heights on the mailed questionnaire more than 2½ cm higher than their height at the examination. Assuming that most people are fully grown by age 25 and have not shrunk by age 48, we dropped questionnaire height and substituted examination height for

TABLE 2. Mean Weight by Zygosity

	Weight (kg)	
	MZ	DZ
Induction	65.6	67.2
Age 25	72.3	72.9
Questionnaire	78.5	79.6
Examination	78.4	79.0

TABLE 3. Mean Height by Zygosity

	Height (cm)	
	MZ	DZ
Induction	173	174
Age 25	*	*
Questionnaire	177	177
Examination	175	175

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age 25 and beyond. Comparison of the mean examination height to the mean induction height shows a 1–2 cm increase, indicating that many of the twins were still growing at the time of induction.

Table 4 presents the Quetelet Index at induction, at age 25, at the time of the mailed questionnaire, and at the examination. As noted earlier, all but the value at induction used the height as measured at examination to reduce error. Q.I. for MZ twins were consistently less than, or equal to, DZ twins at every point although not by large amounts. For comparison purposes, consider the data in Table 5, which shows values of the Q.I. for heights of 173 and 175 cm and weights of 65.5, 67.3, 79.5, and 90.9 kg. These values for height reflect the heights closest to the twins' mean values from induction to examination. The weights 65.5 and 67.3 kg represent the values of "ideal" weight for the heights 173 and 175 cm, respectively, as described by the Metropolitan Relative Weight Tables [8]. The remaining weights are representative values for overweight men who are 175 cm tall. Comparisons indicate that the MZ twins at induction are at "ideal" weight while DZ twins are a bit more obese. However, as their ages increase, the mean indices for MZ and DZ twins increase and in fact are equal at the examination. With average height of approximately 175 cm, this corresponds to a weight of about 79.5 kg as seen in Table 5.

Table 6 displays the intraclass correlations and heritability estimates for the Q.I. at each point in time. Correlations are highest for the MZ and DZ twins at induction and examination when the data were measured. However, the lowest correlation for MZ twins was 0.62 at age 25. For DZ's the correlation at age 25 was 0.29, which is below the range of 0.41–0.43 of the other three values. Heritability estimates ranged from 0.80–0.51 and generally declined with time. Because of a significant difference in total variances, the among-component estimate of genetic variance was used for the estimate using questionnaire data and was not statistically significant ($P = 0.06$). All other estimates of genetic variance were statistically significant ($P < 0.001$).

TABLE 4. Quetelet Index by Zygosity

	Q.I. value	
	MZ	DZ
Induction	2.19	2.22
Age 25	2.36	2.37
Questionnaire	2.50	2.52
Examination	2.57	2.57

Q.I. = $1000 \times$ weight(kg)/height^2(cm)

TABLE 5. Selected Heights and Weights and the Corresponding Quetelet Index

Height (cm)	Weight (kg)	Q.I.
173	65.5	2.19
175	67.3	2.19
175	79.5	2.60
175	90.9	2.97

Q.I. = $1000 \times$ weight(kg)/height^2(cm)

Table 7 provides the results of a twin analysis of change in Quetelet Index from induction to examination. Note these are the data points at which both height and weight were measured. The mean increase in Q.I. for MZ twins was 0.38 versus an increase of 0.35 for DZ twins. Variances of these estimates were also very similar. Intraclass correlations of 0.63 and 0.33 were significantly different ($P < 0.001$) and lead to a heritability estimate of 0.60.

Table 8 is a similar analysis to that of Table 7. It presents results of a twin analysis of change in Q.I. from maturation (age 25) to examination. In this case height used to calculate Q.I. is the measured height at examination. Again, the mean changes in Q.I. and the variances for MZ and DZ twins are very similar. Intrapair correlations of 0.48 and 0.13 were smaller than those of Table 7 for both MZ and DZ twins; however the difference was still statistically significant ($P < 0.001$). The heritability estimate was 0.71 for the change in Q.I. over the approximately 23-year period.

TABLE 6. Heritability Estimates for Quetelet Index

	r_{mz}	r_{dz}	h^2
Induction	0.83	0.43	0.80*
Age 25	0.62	0.29	0.67*
Questionnaire	0.66	0.41	0.51**
Examination	0.71	0.42	0.57*

*Equal total variances for MZ and DZ twins; $P < 0.001$ for test of genetic variance.
**Unequal total variances for MZ and DZ twins; $P = 0.06$ for test of genetic variance.

TABLE 7. Twin Analysis of the Change in Quetelet Index From Induction to Examination

	MZ	DZ
Mean	0.38	0.35
Variance	0.086	0.081
r	0.63	0.33
$h^2 = 2(r_{mz} - r_{dz}) =$	0.60*	

*$P < 0.001$.

TABLE 8. Twin Analysis of the Change in Quetelet Index From Age 25 to Examination

	MZ	DZ
Mean	0.22	0.21
Variance	0.072	0.077
r	0.48	0.13
$h^2 = 2(r_{mz} - r_{dz}) =$	0.71*	

*$P < 0.001$

DISCUSSION

Longitudinal study of height, weight, and of Quetelet Index as a measure of obesity was possible by compiling data from various sources. Weight and height, as measured at induction and as measured at examination, were assumed to be accurate. The consistency, with measurements, of the weight values provided through a mailed questionnaire was encouraging, even though subjects were required to recall weight from 23 years earlier. Values for height from the questionnaire were less reassuring. The majority of subjects tended to provide responses at least 2.5 cm larger than measured values taken within 5 years of the questionnaire mailing. For this reason, questionnaire heights were ignored and examination height was used to calculate Q.I. at age 25 and at examination. Induction height was retained as many of the twins were not fully grown at the time of induction. Mean height increased by over 1 cm from induction to examination, which is not surprising in that the lowest induction ages were 15 years.

Weight gain from induction to age 25, the approximately 5-year interval which represented growth for some of the twins, was 6–7 kg. During the next 23 years the twins averaged another 6 kg of weight gain even though height probably remained constant. At induction, the mean Q.I. was very close to "ideal" relative weight as defined by Metropolitan Relative Weight Tables. By the time they reached age 25, two thirds of the twins were above "ideal" weight. Finally, 23 years later, not only is the mean Q.I. substantially above ideal weight but only 13% of the distribution of men are at or below "ideal" weight.

This fact becomes more interesting when we consider that these men are not representative of the general population since they had to pass an induction physical examination, survive to middle age, and volunteer to be part of the NHLBI Twin Study. Comparison with men in the Framingham Offspring Study of comparable age and measured in approximately the same year, shows the twins to be less obese as measured by Q.I. [4].

Cross-sectional analyses of Q.I. show the largest heritability estimate (0.80) at induction. At this point in their lives members of a twin pair had probably been exposed to very similar environments. The average number of years lived together for MZ and DZ twins was 21 and 20 years, respectively. After induction their environments became less similar and, correspondingly, heritability dropped to the range of 0.5. Correlations did indeed remain high ($r_{mz} = 0.71$ and $r_{dz} = 0.42$) even at age 48.

The tendency to gain weight as evidenced by both the analysis of change from induction, while the twins were still growing, and from age 25 to age 48, appears to be strongly genetically controlled. Heritability estimates of 0.6 to 0.7 demonstrate very strong evidence of this. The heritability for change in Q.I. from induction to age 48 represents an index of general growth reflecting changes in both height and weight. The heritability for change in Q.I. from age 25 to age 48 represents an index of change in weight after maturation adjusted for body size. Thus, even after skeletal development is complete, change in weight during adult years is genetically influenced.

Twins were not necessarily the same age at induction. Approximately 16% of the twins differed for age at induction by more than one year. By zygosity, 12% of MZ twins and 19% of DZ twins differed in induction age by more than one year. Limiting the analyses of change in Q.I. to those twins who were inducted within one year of one another yielded higher heritability for change in Q.I.: 0.65 versus 0.60 for change in Q.I. from induction to examination and 0.89 versus 0.71 for change in Q.I. from age 25 to examination.

In all of these analyses we have assumed equal environmental covariances for MZ and

DZ twins. Certainly no one would dispute the influence of environment on weight change. To the extent that similarity of environments for MZ and DZ twins are not equal these results may be biased. Consider the relationship $r_{mz} = 2r_{dz} = 2(r_{mz} - r_{dz}) = h^2$. These expressions represent three measures of heritability under the circumstances of no environmental covariance for MZ twin, no environmental covariance for DZ twins, and equal environmental covariances for MZ and DZ twins, respectively. The heritabilities of change in Q.I. from induction to examination seem quite consistent: 0.63, 0.66, 0.60. However, the change from age 25 to examination is not so good, namely, 0.48, 0.26, and 0.71. Equal shared environment among MZ and among DZ twins will make $r_{mz} < 2r_{dz}$, but the opposite is true for change in Q.I. from age 25 to examination. It is possible that there is much more concordance in the response error of the MZ than of the DZ twins in estimating weight at age 25. An indication that this may be true can be seen by comparing the correlation of errors in height estimates (questionnaire height – examination height) for MZ and DZ twins. Values of $r_{mz} = 0.33$ and $r_{dz} = 0.24$ indicate greater consistency of reporting errors for height among MZ twins, which may be indicative of comparable errors for estimates of weight at age 25. Certainly the consistency of estimates for change in Q.I. from induction to examination when data were measured and not subjectively recorded is reassuring.

Finally, it should also be noted that these results were obtained from a group of twins living in an environment where almost the entire population is obese. Similar analyses done in populations that distribute more equally around "ideal" weight may show different results.

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