Ann. Hum. Genet., Lond. (1975), 38, 321
Printed in Great Britain

Phenylthiocarbamide tasting in a sample of twins

By N. G. MARTIN*

Department of Genetics, University of Adelaide, South Australia

Harris & Kalmus (1949) and earlier workers found a bimodal distribution of taste thresholds for the substance phenylthiocarbamide (P.T.C.) in European populations. The classical explanation for this distribution is that 'non-tasters' are homozygous for an autosomal recessive gene *t* while 'tasters' are composed of heterozygotes and homozygotes for the dominant allele *T*. Kalmus (1958, 1971) discussed several factors which contribute to variation within the taster and non-taster classes. General sensitivity to bitter substances such as quinine is correlated with sensitivity to P.T.C. within each mode. Increasing age and male sex are associated with lower sensitivity and these also contribute to variation within the two classes. The incomplete dominance of the *T* allele contributes to variation in the 'taster' class. From sib data of Harris & Kalmus (1951) and Das (1956), Kalmus estimated that the mean tasting threshold of heterozygotes (*Tt*) is 1·4 units below that of homozygotes (*TT*).

Partly on the basis of his findings of extraordinarily high taste acuities among some civilized and uncivilized peoples, Lugg (1970, 1974) has criticized the two-allele hypothesis and has proposed a multi-allelic series to account for the variation in threshold he has observed.

In the course of a wider study of the inheritance of scholastic abilities, 46 pairs of same-sex twins were tested for their ability to taste P.T.C. using the method of Harris & Kalmus (1949). Because of the considerable genetic variation in ability to taste this substance we might expect to find greater variance in threshold levels within dizygotic (DZ) twin pairs than within monozygotic (MZ) pairs. If alleles additional to the two generally postulated occur at significant frequencies in European populations, or if there are background genes which significantly modify the acuities primarily determined by the alleles at the major locus, then we should expect to find variation within DZ pairs which could not be accounted for in terms of differences in acuities of the genotypes *TT*, *Tt* and *tt* and by small environmental differences and errors of measurement.

METHOD

The twin pairs were ascertained from the records of a local public examination. They were all of European descent and aged between 19 and 21 years at the time of testing. Zygosity was determined by typing each twin for eight blood group systems and the serum protein haptoglobin. The probability of a pair of twins being concordant for all nine markers if they were in fact DZ is less than 5% (cf. Smith & Penrose, 1955). Hence the 28 twin pairs concordant for all markers were taken to be MZ and the remaining 18 pairs who differed in at least one marker were taken to be DZ. The details of ascertainment and zygosity determination will be published elsewhere.

The dilution series used by Harris & Kalmus (1949) to determine the P.T.C. tasting threshold of subjects is $0{\cdot}26\,\% \times 2^{-n}$ where n ranges from 1 to 13. We used an additional dilution where $n = 0$ and the solutions are correspondingly called 0 to 13. These were freshly made up each week

* Present address: Department of Genetics, University of Birmingham, Birmingham, B15 2TT.

Table 1. *Taste thresholds for P.T.C. for 46 pairs of same-sex twins classified by zygosity and sex*

MZ male		MZ female		DZ male		DZ female	
10	11	11	12	10	10	11	9
10	10	11	11	9	9	9	11
10	10	10	10	9	7	9	10
10	9	10	10	8	9	9	10
10	9	10	10	8	1	9	9
9	10	10	10	1	0	9	8
9	9	10	10			9	1
9	8	10	10			4	10
8	9	10	9			3	7
2	2	9	9			2	9
		9	9			2	3
		9	8			< 0	9
		3	1				
		2	1				
		1	1				
		1	1				
		0	2				
		0	0				
10 pairs		18 pairs		6 pairs		12 pairs	

with reagent quality phenylthiourea (P.T.C.) (British Drug Houses) in distilled water. Boiled tap water recommended by Harris & Kalmus was of too variable quality to be used.

Before testing was started, the subject sipped some distilled water in case the taste was unfamiliar. The subject used a clean plastic teaspoon for each test and rinsed his mouth out with distilled water each time he claimed to detect P.T.C. He was encouraged to spit out the tested liquid, particularly as he moved to more concentrated solutions (< 7), in view of the possible toxicity of P.T.C. reported by Wheatcroft & Thornburn (1972). If at any stage the subject complained of taste fatigue the test was suspended for at least ten minutes. Each twin was tested without knowledge of his co-twin's threshold.

RESULTS

The tasting thresholds for the 46 twin pairs are shown by zygosity and sex in Table 1. The first threshold of a pair is that for the twin who claimed to be first born.

By limiting comparisons to those differences within like-sex twin pairs, there is no need here to consider corrections for age and sex differences. The intrapair variance for n pairs of twins is given by

$$s_{ip}^2 = \frac{\sum_{i=1}^{n} (x_{i,1} - x_{i,2})^2}{2n}$$

where $x_{i,1}$ and $x_{i,2}$ are the thresholds of the two twins of the ith pair. These variances are shown for MZ and DZ classes in Table 2.

Earlier workers considered the antimode of the distribution at thresholds 5, 6 and 7 as the division between 'tasters' and 'non-tasters'. Harris & Kalmus (1951) and Das (1956) analysed their data first taking this division between thresholds 5 and 6 and secondly between thresholds

Table 2. *Intrapair variances, s_w^2, for MZ, DZ and concordant DZ classes*

Class	No. twin pairs	s_w^2	
MZ males	10	0·300	$F_{18,10}$ = 1·11 (2 tail, P = 0·90)
MZ females	18	0·333	
DZ males	6	4·583	$F_{12,6}$ = 2 52 (2 tail, P = 0·26)
DZ females	12	11·542	
DZ concordant males	5	0·600	$F_{7,5}$ = 1·43 (2 tail, P = 0·72)
DZ concordant females	7	0·857	
DZ both sexes	18	9·222	$F_{18,28}$ = 28·69 (1 tail, P < 0·001)
MZ both sexes	28	0·321	$F_{12,28}$ = 2·33 (1 tail, P = 0·03)
DZ concordant both sexes	12	0·750	

6 and 7. None of the twins had thresholds of 5 or 6 so the choice of which of these two division points to use here is immaterial. Twins with thresholds greater than 6 can be classified 'tasters' and those less than 6 as 'non-tasters'. By this criterion one DZ male pair and five DZ female pairs are classified as discordant for tasting ability leaving five male and seven female concordant DZ pairs for comparison with the MZ classes in Table 2. In the calculation the threshold < 0 is taken as -1.

Two-tailed F tests show no significant differences between the sexes of the MZ, DZ and concordant DZ classes. When the variances for the sexes in each class are pooled, very much greater variance in threshold (one-tailed test) is observed within DZ than within MZ pairs.

Variance within MZ pairs can only be due to environmental differences encountered by the two twins and to errors of measurement. If there are environmental factors which alter P.T.C. taste acuities, smoking and eating habits have repeatedly been shown not to be among them (Freire-Maia, 1968; Lugg, 1974). Presumably any such sources of variation that do occur make the same contribution to differences between DZ twins. Any additional variance found within DZ pairs must be genetic in origin.

Lugg (1974) has calculated the intrapair variance of first and repeat threshold measurements carried out on a total of 89 subjects by Harris & Kalmus (1949), Lugg & Whyte (1955) and Das (1956). Although the three sets of data are not strictly homogeneous it is interesting to compare the combined estimate of 0·242 with the intrapair variance of the 28 MZ twin pairs. The two do not differ significantly ($F_{28,89}$ = 1·33, P = 0·16), indicating that most of the variance in threshold within MZ pairs is due to day-to-day variability and to errors of measurement.

It is also interesting to compare the variance of the concordant DZ pairs with that for 247 sib pairs concordant for P.T.C. tasting ability who were tested by Harris & Kalmus (1951). This latter variance is 1·573 which does not differ significantly from that for the concordant DZ pairs (1 tail, P = 0·07) but is much greater than the variance within MZ pairs (P < 0·001).

The much greater variance in threshold within DZ pairs than within MZ pairs confirms the high degree of genetic determination of ability to taste P.T.C. Furthermore, the variance within concordant DZ pairs is significantly greater than that within the MZ pairs and this shows that there are heritable differences in P.T.C. threshold which cannot be explained by the simple model in which the T allele is completely dominant over t. Before we invoke other alleles or background genes to explain this difference we may calculate how much of it can be attributed to the incomplete dominance of the T allele postulated by Kalmus.

Table 3. *Expectations, expected and observed numbers in the five classes of twin pairs*

	Expectation	Expected number	Observed number
MZ			
Both $T-$	$\frac{23}{46}(1-q^2)$	20·54	21
Both tt	$\frac{23}{46}q^2$	7·46	7
DZ			
Both $T-$	$\frac{18}{46}\{(1-q)(1+q)-\frac{1}{4}q^2(1-q)(3+q)\}$	11·17	10
One $T-$, one tt	$\frac{18}{46}\{\frac{1}{2}q^2(1-q)(3+q)\}$	4·08	6
Both tt	$\frac{18}{46}\{\frac{1}{4}q^2(1+q)^2\}$	2·75	2
Total	1	46	46

Suppose the difference between the means of homozygous and heterozygous tasters is D. Let P denote the probability that, given that a pair of DZ twins are both tasters, they are either both homozygotes or both heterozygotes, and let Q be the probability that, given that they are both tasters, one is a homozygote and one a heterozygote so that $P+Q = 1$. If the threshold difference between a pair of twins TT, Tt, due to incomplete dominance, is D and this is arbitrarily measured as the score of the 'first' twin minus the score of the 'second' then we expect a proportion $Q/2$ of concordant taster DZ pairs to have threshold difference $+D$ and a proportion $Q/2$ to have difference $-D$. The mean difference of concordant taster DZ pairs, due to incomplete dominance, will be 0 and the variance which we may call

$$V_{\text{id}} = P\times 0^2+(Q/2)\times(+D)^2+(Q/2)\times(-D)^2 = QD^2.$$

Using the sib–sib frequencies from Table 5 of Smith & Penrose (1955) we find

$$Q = \frac{q(1-q)(2-q)}{1+q-\frac{1}{4}q^2(3+q)},$$

where q is the frequency of the t allele.

We estimate q by the method of maximum likelihood using the expectations and observed numbers for all five classes of twin pairs shown in Table 3. The expectations for the three DZ classes are sib–sib frequencies from Smith & Penrose (1955).

When the likelihood expression is maximized, $q = 0{\cdot}52 \pm 0{\cdot}06$ which is close to other estimates of the frequency of t in European populations (Harris & Kalmus, 1951; Lugg & Whyte, 1955). This result can be more directly obtained from the scores and their weights for related individuals given by Fisher (1940).

Taking Kalmus' value of $D = 1{\cdot}4$ threshold units, at this value of q, $V_{\text{id}} = 0{\cdot}56$.

The expected numbers in each class are also shown in Table 3. In testing the goodness of fit we lose one degree of freedom in estimating q, another by using the observed ratio of MZ to DZ pairs and a third because we have to amalgamate the last two classes which have small expected numbers. This leaves us with $\chi^2_1 = 0{\cdot}36$ ($0{\cdot}5 < P < 0{\cdot}7$), showing good agreement between the data and the two-allele hypothesis.

CONCLUSION

If the greater variance in thresholds within concordant DZ pairs is due only to incomplete dominance of the T allele then we should find

$$V_{\text{DZ}} \simeq V_{\text{MZ}}+V_{\text{id}},$$

where V is the variance of a difference and is twice the within-pair variance. In fact $V_{DZ} = 1{\cdot}50$ and $V_{MZ}+V_{id} = 1{\cdot}20$. If the comparison is restricted to the 21 MZ taster pairs and the 10 DZ concordant taster pairs $V_{DZ(T)} = 1{\cdot}60$ and $V_{MZ(T)}+V_{id} = 0{\cdot}98$. The standard error of $V_{DZ(T)}$, based on only 10 pairs, will be approximately 0·72 which more than covers the discrepancy between $V_{DZ(T)}$ and $V_{MZ(T)}+V_{id}$. In either comparison it seems that incomplete dominance of the T allele is sufficient to account for the extra variance observed within concordant DZ pairs. It is not necessary to invoke other alleles or background genes in this European population to explain the extra variance although this does not exclude their existence. These two possibilities cannot be tested separately with this kind of data but the operation of either background genes or other alleles or both could be tested by comparing MZ and DZ twin pairs classified as concordant for non-tasting. The sample size is too small to permit such a comparison here.

SUMMARY

1. Twenty-eight pairs of monozygotic and eighteen pairs of dizygotic twins were tested for their ability to taste phenylthiocarbamide (P.T.C.) by the method of Harris & Kalmus (1949).

2. Much greater variance in threshold levels was detected within the DZ than within the MZ pairs and this confirms the genetic origin of most variation in ability to taste this substance.

3. Variance in threshold levels within MZ pairs is of the same magnitude as the variance of reported duplicate measurements on the same individuals.

4. DZ twin pairs were classified as either concordant or discordant in their tasting ability. Variance within concordant DZ pairs is significantly greater than within the MZ pairs and it is shown that this difference can be accounted for in terms of the incomplete dominance of the T allele reported by Kalmus (1958). However, the data do not exclude the possibility that this greater variation in threshold levels is partly due to multiple alleles or background genetic variation.

5. The frequency of the t allele in Australians of European descent is estimated at $0{\cdot}52 \pm 0{\cdot}06$.

I should like to thank the twins for their cooperation in the taste testing and Professor J. W. H. Lugg, Professor J. H. Bennett, Professor C. A. B. Smith, Professor N. S. Stenhouse, Dr B. W. Gabb and Dr G. M. E. Mayo for helpful advice and criticism.

REFERENCES

Das, S. R. (1956). A contribution to the heredity of the P.T.C. taste character based on a study of 845 sib-pairs. *Annals of Human Genetics* **20**, 334–43.

Fisher, R. A. (1940). The estimation of the proportion of recessives from tests carried out on a sample not wholly unrelated. *Annals of Eugenics* **10**, 160–70.

Freire-Maia, D. V. (1968). Does smoking affect taste sensitivity to phenylthiourea? *Eugenics Quarterly* **15**, 51–4.

Harris, H. & Kalmus, H. (1949). The measurement of taste sensitivity to phenylthiourea (P.T.C.). *Annals of Eugenics* **15**, 24–31.

Harris, H. & Kalmus, H. (1951). The distribution of taste thresholds for phenylthiourea of 384 sib pairs. *Annals of Eugenics* **16**, 226–30.

Kalmus, H. (1958). Improvements in the classification of taster genotypes. *Annals of Human Genetics* **22**, 222–30.

Kalmus, H. (1971). Genetics of taste. In *Handbook of Sensory Physiology*, IV(2), *Taste*, ed. L. M. Beidler. Berlin: Springer-Verlag.

Lugg, J. W. H. (1970). Unusually high taste acuity for phenylthiocarbamide in two Formosan aboriginal groups. *Nature, London* **228**, 1103–4.

LUGG, J. W. H. (1974). On the multimodality of frequency distributions of the thresholds of taste for phenylthiocarbamide in human population groups (in preparation).

LUGG, J. W. H. & WHYTE, J. M. (1955). Taste thresholds for phenylthiocarbamide of some population groups. I. The thresholds of some civilized ethnic groups living in Malaya. *Annals of Human Genetics* **19**, 290–311.

SMITH, S. M. & PENROSE, L. S. (1955). Monozygotic and dizygotic twin diagnosis. *Annals of Human Genetics* **19**, 273–89.

WHEATCROFT, P. E. J. & THORNBURN, C. C. (1972). Toxicity of the taste testing compound phenylthiocarbamide. *Nature New Biology* **235**, 93–4.