THE EFFECT OF GENETICALLY-MEDIATED TASTE ACUITY FOR 6-N-PROPYLTHIOURACIL (PROP) ON FOOD CHOICE AND DIET-RELATED DISEASE

PAMELA MADDEN

Doctor of Philosophy

ASTON UNIVERSITY

September 2001

SYNOPSIS

The effect of genetically-mediated taste acuity for 6-n-propylthiouracil (PROP) on food choice and diet-related disease. Pamela G. Madden. Doctor of Philosophy. Aston University. 2001.

Taste acuity for the bitter taste of 6-n-propylthiouracil (PROP) is a heritable trait. Some individuals perceive concentrated levels of PROP to taste extremely bitter (supertasters) or moderately bitter (medium tasters), whereas others detect only a mild taste or none at all (non-tasters). Heightened PROP acuity has been reported to be associated with greater acuity for a variety of compounds found in ordinary foods, although there are some inconsistent findings. The extent to which these compounds are perceived may affect food likes/dislikes and dietary intake. The majority of studies have tended to measure food likes and intake using questionnaires or laboratory preparations of a single taste quality. The present study used food diaries and sensory responses to real foods to be better able to generalise to real eating situations. There was no substantial evidence that genetically mediated taste acuity for PROP had a direct influence on food likes/dislikes or intake, although there was evidence that dietary restraint could have influenced these findings among the female samples. However, investigation of PROP tasting among individuals with coronary heart disease (CHD) and a control group, suggested that PROP acuity could function as a genetic taste marker for heart disease and potentially other diet-related conditions. CHD was associated with decreased PROP acuity among men. This is consistent with the findings that decreased PROP acuity tended to be associated with increased likelihood to be a smoker and higher body mass index. It is concluded that there is not a simple and direct relationship between PROP tasting ability and food choice. An interaction between PROP acuity and other mediating factors may be involved in a more complex model of food choice. The evidence that PROP taste acuity may function as a genetic taste marker for coronary heart disease cold have wide implications for understanding the aetiology, and ultimately the prevention, of diet-related disease.

Keywords: Supertasters, food likes/dislikes, dietary intake, coronary heart disease, psychophysics.

ACKNOWLEDGEMENTS

I would like to express my immense appreciation to Dr Marie Falahee, my internal supervisor, for her invaluable guidance, encouragement, and faith in me. I am also extremely grateful to my associate supervisor Dr Richard Freeman for his much appreciated advice and feedback throughout, especially during the latter stages. Thanks also to Dr Michael Green for agreeing to take on the role of supervisor towards the end, and for his feedback on the final draft.

I would also like to thank Dr Fiona Fylan for her insightful feedback on my first year report, including inspiring the final study. Thanks also to Dr Aisling Armstrong for her dietetic advice. Massive thanks to Niteen Mulji and Bob Godwin for helping me out with technical problems, saving the day on several occasions. A special thanks to Hilary Campbell for helping me to develop my writing skills.

Thank you to my parents for their endless support, and for the relaxing breaks at home in Ireland. Thanks to Susan, sister and star reference typist in first year. Thanks to my friends for all the nights out and days away, many for going through the PhD experience with me.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

Chapter One

Determining PROP Taster Status: Background to Methods Used in Thesis

1.1 Introduction to Thesis

Fox (1931) discovered by accident that some people perceive the taste of phenylthiocarbamide (PTC) to be bitter whilst others perceive it to have no taste at all. Whilst placing PTC in a bottle some of it escaped into the air. A colleague commented that it tasted bitter whilst Fox himself, who was considerably closer, did not notice any taste at all. After investigating the phenomenon with a larger sample he described the inability to taste this compound as "taste blindness" since he thought it to be similar in its manifestations to colour blindness. He labelled those who could not detect a taste as "non-tasters" and those who could as "tasters".

Both PTC and PROP (6-n-propylthiouracil) are phenothioureas, a class of about forty compounds which all contain an H-N-C=S molecule grouping. This compound, particularly the C=S linkage, is thought to be responsible for their bitter taste (Shallenger and Acree, 1971). PROP is preferred over PTC in current studies for determination of taster status because it is odourless and toxicity data are available (Fischer, 1971). In contrast, PTC solutions have a faint sulphurous smell in high concentrations. This may create problems in studies of taste because the participants may use odour cues rather than, or in addition to, their perception of taste. Safety limits in exposure to PROP are known because it is used as a medication to treat Grave's Disease (hyperthyroidism). Filter paper impregnated with a saturated solution contains about 1.2mg of PROP (Duffy and Bartoshuk, 1996a) whereas the recommended dose for those with Grave's Disease is between 50 to 600mg per day (Solomon, 1986).

The term non-taster is now used to describe individuals who perceive concentrated PTC or PROP to be mildly bitter or barely detectable, rather than only those who detect no taste at all. "Tasters" represent a diverse population whose detection thresholds of PROP can vary by several orders of magnitude. Linda Bartoshuk and her colleagues (Bartoshuk et al., 1992) were the first to achieve functional separation of the taster group, the most sensitive of which were named "supertasters". Medium tasters perceive a moderately bitter taste whereas supertasters perceive an extremely bitter taste from concentrated PROP solutions.

Different abilities in taste perception of phenylthioureas represent variations in normal taste function. Non-tasters do not have a taste dysfunction. However chemosensory disorders can alter PROP/PTC taster status and result in misclassification.

The distribution of PTC and PROP thresholds has been found to be roughly bimodal. One of the distributions is the non-taster distribution. The medium taster and supertaster distributions are overlapped (Bartoshuk, 1993). Individuals with thresholds equal to or lower than 0.0001 M PROP (the antimode) are considered to be tasters, and those with thresholds equal to or higher than 0.0002 M PROP are considered to be non-tasters.

Relationships between PROP tasting ability and acuity for other tastes will be reviewed in Chapter Two. How PROP acuity relates to food intake, food likes/dislikes, and ultimately, diet-related disease, will be examined in Chapters Three, Four, and Five respectively. However, it is important to first be aware of the methodological issues involved in PROP research in order to obtain a full appreciation of the existing literature.

1.2 Introduction to Background of Methods Used in This Thesis

Fox's discovery that individuals vary in their taste perception of phenylthiocarbamide (PTC) led him to attempt to separate and label tasters and non-tasters. His method of distinguishing between these two groups was simply to place PTC crystals on the tongue (Harris and Kalmus, 1949). Those who detected a taste were labelled tasters and those who did not were termed non-tasters. This method was very crude and improved methods of determining taster status have been put forward and implemented since.

The existing methods of determining taster status attempt to measure the absolute threshold and/or suprathreshold responses. These procedures are described and evaluated below, and comparative studies also reviewed. The overall objective was to use this information to select a method of determining PROP taster status that could be used in this thesis. A second aim was to appreciate some of the strengths and limitations of methods used in earlier studies as well as studies using current methodologies.

1.3 Early Methods

Whilst some initial research used Fox's crystal approach to distinguish between tasters and non-tasters (e.g. Snyder, 1931), other contemporaries sought to investigate differential acuity amongst tasters. To do this, Blakeslee and Salmon (1931) used a serial dilutions approach. Five solutions of PTC crystals, each four times stronger than the next, were presented in ascending concentration (initial level: one part PTC to 1,280,000 parts water). The first solution that was reported to have a taste, and was correctly described as bitter, was taken as the threshold. Those who could not detect a taste from any of these solutions were classified as non-tasters. Although this method was a worthy first step in improving upon the use of raw crystals, it still remained quite unrefined. Two problems were that the step between solutions was rather large, and that participants were required not only to perceive a taste but also correctly name it as bitter, both of which could potentially have inflated the true threshold values.

Hartman (1939) found good agreement between the crystal and serial dilutions methods of identifying tasters, but some dissociation in the classification of non-tasters. Almost every taster identified using thresholds perceived a taste from the crystals, as did 17% of the non-tasters. However the strongest PTC solution was ten times weaker than a concentrated solution and thus much weaker than the raw crystals. Therefore a taste is more likely to be perceived from the crystals than the solutions so perhaps agreement between the two methods should not be expected.

1.4 The Harris-Kalmus (1949) Procedure

The first standardised method of classifying people according to their taste sensitivity was put forward by Harris and Kalmus in 1949. Their method used fourteen solutions of PTC, ranging from 0.0000012 M (solution 14) to 0.00845 M (solution 1), each successive solution being twice as strong as the next. The Harris-Kalmus method proceeded in two stages. The first stage determined an approximate threshold. Participants were asked to identify the first solution which they perceived to have a taste from an ascending concentration series. During the second stage the participant was presented with eight small tumblers, four of which contained the solution selected in stage one, and four of which contained boiled tap water. The participant's task was to sort the samples into those that had a taste and those that did not. If the task was performed correctly the PTC concentration was decreased by half until an incorrect discrimination occurred. The threshold was taken as the lowest concentration at which the participant gave a correct response. If, however, the respondent could not sort the first set of stimuli accurately, the test was repeated with increasing concentrations until a correct answer was given. The labels "taster" or "non-taster" were assigned by plotting the distribution of taste thresholds within a sample. These distributions were bimodal and the antimode was taken as the cut-off point between tasters and non-tasters.

One advantage of the Harris-Kalmus method is that the threshold value is quite easy to determine (Harris and Kalmus, 1949). This is partly because it is not very time consuming as well as its being straightforward in nature. Harris and Kalmus reported that the reliability of this method was very good. However, this conclusion was based on the configuration of a scatterplot between thresholds measured both initially and several weeks later - a correlation value was not given to support this interpretation.

Given that the Harris-Kalmus procedure tries to strike a balance between reliability and the ability and perseverance of the participant, Kalmus acknowledged that their choice of criterion "sacrifices accuracy for speed" (Kalmus, 1971, p.167). However he asserted that the large range of sensitivities makes this criterion acceptable, and classification errors are not numerous. Therefore the sacrifice may be justified especially when practical considerations such as time constraints are recognised.

Minor weaknesses of the Harris-Kalmus test led to the introduction of several modifications in an attempt to refine it. Lawless (1980) summarised several variations of this method. These included: the use of distilled water as a solvent rather than boiled tap water; the use of an interstimulus rinse; the use of PROP rather than PTC; allowing only one tasting of each stimulus rather than ad lib sipping. Kalmus (1971) modified the procedure by allowing the participant to try the same concentration again if he/she sorted all but one pair correctly. If more than one pair was incorrect a stronger solution was administered. However a problem raised by Kalmus (1958) has not been addressed. He reported that although the original 1949 version was "adequate for individuals having high and low thresholds, it is rather uncertain for a small number of intermediate thresholds near the antimode" (Kalmus, 1958, p.222). He suggested that the determination of PROP taster status could be improved by measuring the threshold for a bitter substance that does not contain the C-N=S grouping in PTC (and PROP). Individuals with a PTC threshold at the antimode and a high (low) sensitivity to quinine were considered to be non-tasters (tasters), a finding confirmed by Fischer (1971). However this modification was not adopted by later researchers and so the problem remained.

1.5 The Staircase Method

The modified up-down or staircase method (Cornsweet, 1962) is similar to the Harris-Kalmus method. Instead of having to sort four PROP solutions from four water samples, the respondent is presented with just one PROP solution and one water sample. He or she is told that one of the pair has a taste and the other is water and asked to identify the one thought to have a taste. This forced choice element was incorporated into Cornsweet's original method in which the solution was presented alone and the participant had to decide whether or not it had a taste. If the participant correctly identifies the correct sample from the pair, the concentration of the solution is decreased. If the response is incorrect, a higher concentration is presented. This procedure is continued through several reversals, a reversal point being the concentration at which an incorrect choice follows a correct choice or the point at which a correct choice follows an incorrect choice.

According to Cornsweet the experimenter must decide in advance: 1) where to start the series; 2) how large the steps are; 3) when the series should end. As in the Harris-Kalmus procedure, this method should begin by determining an approximate threshold. Drewnowski and Rock (1995), in a review paper, reported that current methods require fifteen PROP solutions ranging in concentration from 0.000001 M (solution 1) to 0.0032 M (solution 15) that increase in one-quarter log increments on the molar scale.

The rule of thumb in the literature is to stop the series after five to seven reversals. The first reversal is usually discarded and the mean of the subsequent reversals is calculated to determine the final threshold value. PROP non-tasters have been defined as having thresholds greater than 0.0002 M PROP (solution 10), medium tasters and supertasters as having PROP detection thresholds less than 0.0001 M PROP (solution 9; Bartoshuk, 1993).

Problems arise when the concentration of a solution is decreased after it is correctly identified only once. Larry Marks analysed this and found that if you begin to determine the threshold using an approximate threshold solution that is too low, this sequence will generate nonsense thresholds (Linda Bartoshuk, personal communication). Consequently there will be misclassifications when participants are grouped into non-tasters, medium tasters, and supertasters. A Wetherill and Levitt (1965) modification deals with this problem. The stimulus intensity is increased after an incorrect response as before, but decreased after two consecutive correct responses instead of one. Increasing the number of correct responses required increases the reliability of the threshold, it lies between chance and perfect performance, rather than just chance responding.

The original staircase method was claimed to be extremely efficient. The computation of an approximate preliminary threshold means that fewer stimuli, and thus fewer trials, are required than in other psychophysical methods to arrive at the final threshold value (Cornsweet, 1962). However using the modified version is quite time consuming (Bartoshuk, 1978). To reduce the time required, Bartoshuk suggested that the number of reversals could be decreased, although this will also decrease the reliability, but clearly there must be a trade off between reliability and time efficiency. Another problem associated with this method is that it may be possible for the participant to become aware of the relationship between how he/she responds and the subsequent change in concentration. This may affect his or her decision-making process and criteria on future trials, and manipulated data may be indistinguishable from meaningful data. However, this problem is less likely to occur when a Wetherill and Levitt modification is used. To reduce the potential for bias, Cornsweet suggested running two staircase series concurrently in what he called the "double staircase method". In this procedure each series may appear on every alternate trial, or may be featured randomly. The two series may be considered as two replications or may be combined to compute a single threshold value (Cornsweet, 1962).

Bartoshuk (1993) reported excellent consistency between the up-down/modified staircase method and the Harris-Kalmus procedure. Data from eighty-three participants yielded a correlation coefficient of 0.95, with the up-down thresholds about 0.25 log steps below the Harris-Kalmus thresholds.

1.6 Methods Based on Signal Detection Theory (SDT)

The existence of a sensory threshold and thus the utility of threshold methods have been questioned. According to traditional psychophysics, when a weak stimulus is presented it either can, or cannot, be detected. However it has been argued that the strength of the stimulus and individual sensitivity are not the only factors which influence the response. The methods of measuring thresholds do not take into account the observer's decision-making criteria. According to signal detection theory on every trial the respondent is unsure whether he or she can actually detect a stimulus (a taste in this case) or is imagining it. His or her response will depend upon when they decide that the difference is no longer thought to be imaginary and can be reported as real. This will depend upon the individual's willingness to commit him or herself (O'Mahony, 1990) which is a cognitive rather than a sensory criterion. The response criterion can vary from individual to individual and can vary during the course of an experiment. Methods based on signal detection theory attempt to manipulate and/or measure the criterion used in an individual situation in order to separate cognitive factors and sensory ability.

Psychophysical methods that are compatible with signal detection theory include the yes-no procedure and the rating scale procedure. They allow the effects of the response criterion and the perception of taste to be separated. Swets (1961) argued that data collected with these methods gives good reason to question the existence of sensory thresholds and to doubt whether anything more than a response criterion affects individuals' responses. The yes-no procedure manipulates the participant's criterion by informing him/her of the costs and values of various decision outcomes (or the percentage of trials on which a stimulus will be present). The participant's task is to judge whether a taste was present by answering "yes" or "no". The criterion levels are varied so that if there is a reward for correctly identifying a taste (or if the taste is expected to occur on most trials) the respondent is more likely to say yes than if there is a penalty for wrong identifications (or if the taste is expected to occur rarely).

The yes-no procedure is extremely time consuming in that it requires several hundred trials per person. This may introduce additional problems such as practice and fatigue effects. The rating scale procedure however is a lot more efficient. This method requires the respondent to estimate the certainty about the presence or absence of a taste on a given trial. For example the participant may respond by choosing a number from one to five where one indicates that a taste was not identified, three indicates that he/she is not sure, and five if he/she was certain that a taste was perceived. Each number may be considered to correspond to a different criterion (McBurney and Collings, 1984).

The measure of taste sensitivity in signal detection procedures is d'. This statistic is based on the participant's "hit rate" (i.e. how many times he/she said that a taste was detected when a taste was actually present) and number of "false alarms" (when a taste is said to be detected when a taste *was not* presented). The larger the value of d', the more sensitive the sense of taste of the observer. No study to date has used a signal detection approach to determine PROP taster status. This means that there is no established way to separate the three taster groups using these procedures.

It is possible to control the variation in the criterion without having to resort to using methods based on signal detection theory. According to O'Mahony (1990) this can also be achieved by using a forced choice procedure in threshold methods. The Harris-Kalmus and the modified staircase method incorporate this element. However O'Mahony states that a forced choice strategy is a necessary but not a sufficient condition for controlling criterion variation. The judge must also know the number of unknown stimuli in each class, and have sufficiently few stimuli to be able to make comparisons between them all. Both the Harris-Kalmus and the modified staircase method meet the former condition but O'Mahony thought that it is possible that the eight stimuli used in Harris and Kalmus's task may be too many to compare.

1.7 Suprathreshold PROP Responses - Magnitude Matching and Magnitude Estimation

Thresholds may have limited applied value in studies of food choice. According to Bartoshuk the use of the absolute threshold to see how the same substance tastes to different people, and thus to predict food selection amounts to "looking in the wrong place" (Bartoshuk, 1980, p.351). She argued that researchers should look at higher concentrations that represent those found in actual foods because the sensory mechanisms underlying the absolute threshold perception may not be the same as those that underlie the perception of strong concentrations. Suprathreshold scaling also has the advantage of being able to distinguish medium tasters from supertasters and is often used for this purpose in addition to threshold measurement.

Linda Bartoshuk and her colleagues (Bartoshuk et al., 1992) were the first to achieve functional separation of the taster group into medium tasters and supertasters using suprathreshold scaling procedures. Participants rated the intensity of two suprathreshold concentrations of sodium chloride (NaCl; 0.32 M and 1.0 M) and two suprathreshold concentrations of PROP (0.001 M and 0.0032 M). NaCl was used as a standard because it was found to taste the same to everyone regardless of taster status (Jefferson and Erdman, 1970; Bartoshuk, 1979; Bartoshuk, Duffy, and Miller, 1994; Marks et al., 1988; Mela, 1989, 1990; Sato et al., 1997). Non-tasters tend to rate the bitterness of PROP to be very weak compared to the saltiness of NaCl whereas tasters and supertasters rate PROP bitterness as tasting stronger than NaCl. The ratings of PROP and NaCl were measured using magnitude estimation, a class of psychophysical scaling procedures that were developed by S.S. Stevens in the 1950s. Using this method, the participant assigns a number (the modulus) to the first solution (the standard stimulus) that corresponds to its perceived intensity. The intensity of the other solutions are then given a numerical rating relative to that of the standard. For example, if a solution tasted twice as strong as the standard it was given a number that is twice as large. Bartoshuk's participants rinsed their mouth with water between each of the four samples. Taster status was based upon a ratio value of the intensity ratings of the two PROP solutions relative to those of the two NaCl solutions ([0.001 M PROP/ 0.32 M NaCl + 0.0032 M PROP/ 1.0 M NaCl] /2). Those individuals with a ratio greater than or equal to 1.2 were classified as supertasters (Bartoshuk, 1993). This cut off point was selected because it was the point above which the number of participants equalled those classified as non-tasters using the modified staircase method (there being approximately equal numbers of non-tasters and supertasters in mixed sex samples: 25% non-tasters; 50% medium tasters; 25% supertasters).

The use of magnitude estimation procedures has the advantages of yielding ratio level data and being easy to use (Bartoshuk, 1978). However there are a few recurring biases and problems associated with this method, although most of these can be easily remedied. These include the round number tendency, the end-effect, and the regression effect (Moskowitz, 1977). The round number tendency refers to the tendency of participants to use round numbers rather than thinking in pure ratio terms such as "1.3 times stronger". Thus round numbers such as 1, 5, 10, 20, 50, and 100 come up more often than other numbers. This problem can be remedied by randomising which sample is used as the standard and by letting each participant select his or her own modulus. This helps to distribute frequently occurring numbers along the entire set of stimuli. The end-effect occurs when respondents use a restricted range of numbers. The range of numbers varies among individuals. For example some people may use a range between one and ten, others between zero and one hundred and others between zero and one thousand. The range of numbers could be bounded in order to counteract the end-effect, although this would induce experimenter-induced bias which limits the range arbitrarily (Moskowitz, 1977). The variation in the range of numbers used also leads to the regression effect (Stevens and Greenbaum, 1966). When the numbers (magnitude estimates) are plotted against concentrations of PROP/NaCl, the use of a wide range of numbers yields a steeper slope than when a small range is used, even if the individuals' sensory perception is identical. The regression effect refers to the existence of a flatter magnitude estimate curve when numbers are matched to stimuli than when stimuli are matched to numbers. Moskowitz suggested that to remedy the regression effect the respondent could be asked to match numbers to solutions as well as to match solutions to numbers. The average sensory function will produce a truer value by cancelling out some (but not all) of the regression effect.

1.8 Alternatives to Magnitude Estimation - Category and Simple Line Scales

Adam Drewnowski modified Bartoshuk's method of identifying supertasters (Drewnowski, Henderson, Shore, and Barratt-Fornell, 1997; Drewnowski, Henderson, and Shore, 1997a; 1997b). He used five suprathreshold concentrations of both NaCl and PROP rather than two, and replaced magnitude estimation with a nine-point category ratio scale (1 = not at all salty/bitter, 9 = extremely salty/bitter). The mean ratio of the intensity ratings of the five suprathreshold PROP solutions (0.000032, 0.0001, 0.00032, 0.001, and 0.0032 M) relative to the five NaCl solutions (0.01, 0.032, 0.1, 0.32, and 1.0 M) was calculated using the following formula:

$$\frac{\frac{p_1}{n_1}+\frac{p_2}{n_2}+\frac{p_3}{n_3}+\frac{p_4}{p_5}+\frac{p_5}{n_5}}{5}$$

where $p_{1\text{-}5}$ are the bitterness intensity ratings for five suprathreshold PROP solutions, and $n_{1\text{-}5}$ are the saltiness intensity ratings for five suprathreshold NaCl solutions. To qualify as supertasters, participants had to have a PROP threshold (as measured using the modified staircase method, as Bartoshuk) below 7 and also a PROP/NaCl ratio of 1.7 or more (Drewnowski, Henderson, and Shore, 1997b). However according to Linda Bartoshuk (personal communication) the use of a nine-point category scale introduces severe ceiling effects and cannot be used to calculate a true ratio. This is because category scales cannot measure the distance between responses, they can only order the distances. She asserts that the use of category scales can obscure perceptual differences between the taster groups, and therefore diminish PROP effects at best, or wipe them out entirely at worst. Drewnowski, Henderson, and Shore (1997b) argued that the use of more conservative cut-off points to identify supertasters as well as the wider range of suprathreshold stimuli were employed with the specific purpose of dealing with these ceiling effects.

Tepper and Nurse (Tepper and Nurse 1997a; Tepper and Nurse 1997b) also used 15 cm lines scales as an alternative to magnitude estimation to measure the suprathreshold response. This had the advantages of being easier for the participants to understand and use as well as avoiding some of the problems associated with magnitude estimation. However this method introduced new problems. The authors observed a ceiling effect at the highest concentrations because the participants' judgements were constrained by the upper endpoint of the scale, although they reported that this did not interfere with the ability to reliably classify people into the three taster groups. Tepper and Nurse

(1997a) suggested that the Labelled Magnitude Scale (LMS) developed by Green, Schaffer, and Gilmore (1993) could be a useful alternative in future studies.

1.9 The Labelled Magnitude Scale (LMS)

The Labelled Magnitude Scale is a vertical line with category labels in a quasi-logarithmic distribution (see Figure One). The scale was devised by Green et al. (1993) who compared the LMS with magnitude estimation by asking participants to rate the intensity, chemical irritation, and temperature of sucrose, ethyl alcohol, and distilled water. The agreement between the two methods was reported to be excellent. Therefore it was concluded that the LMS also yields ratio level data. However a later study found that although the LMS produced psychophysical functions equivalent to those produced by magnitude estimation when "strongest imaginable *taste*" was the upper bound, it produced steeper functions when a *specific* taste quality (e.g. strongest imaginable *sweetness/ saltiness/ bitterness*) was rated (Green et al., 1996). Based on these findings the authors concluded that although the Labelled Magnitude Scale is useful when taste is broadly defined, it needs to be modified for use with specific taste qualities.

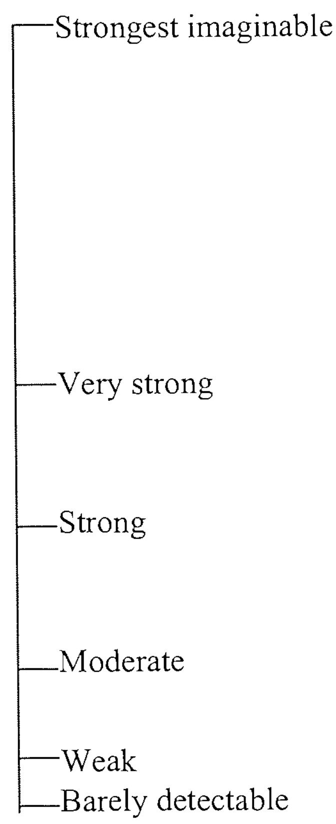

FIGURE 1.1
THE LABELLED MAGNITUDE SCALE

Comparisons of the LMS and category scales reveals that the LMS is better able to identify differences between PROP taster groups as it is continuous and minimises ceiling effects (Lucchina et al., 1998b). It also is easy for participants to understand and use.

1.10 Paper Tests

PROP taster status has also been determined using paper tests. Papers are prepared by soaking filter papers in a saturated PROP solution and leaving them to dry (Bartoshuk et al., 1996). The participant is instructed to place the paper on the tongue, let it moisten, and to rate the intensity of the taste. Ratings have been measured using the Labelled Magnitude Scale (e.g. Freeman et al., 2001) and category scales (e.g. Bartoshuk et al., 1996). The chief advantage of the paper test is that it can be administered very quickly and is therefore the best alternative when large groups need to be tested in a short time.

Paper tests have been criticised but this appears to be largely unjustified. Lawless (1980) reported that paper tests yield false-positive responses (i.e. classified non-tasters as tasters). He compared the paper method with the Harris-Kalmus procedure and found that the agreement between the two methods was good when PTC was used, but was poor when responses were made to PROP. He reported that eight of the fourteen individuals classified as non-tasters according to the Harris-Kalmus method found the PROP paper to taste bitter and claimed that this represented a false positive rate of fifty seven percent. The conflicting findings for the different chemicals may be attributed to the fact that PTC has a faint sulphurous smell. Participants may have used odour cues in addition to their perception of taste to complete the tasks that employed PTC. The poor agreement between the paper method and the Harris-Kalmus procedure when PROP was used cannot be taken as evidence that paper tests are not as good as Harris and Kalmus's more established method. The former attempted to measure suprathreshold responses whereas the latter sought to measure the recognition threshold. Since it has been established that threshold and suprathreshold taste often dissociate (Bartoshuk, 1978; Miller and Bartoshuk, 1991; Bartoshuk, Duffy, and Miller, 1994) the result is not very surprising. Furthermore the Harris-Kalmus method is not faultless and therefore cannot be regarded as the gold standard against which other methods can be judged.

Bartoshuk et al. (1996) found a correlation of 0.6 between the classifications yielded by paper ratings and PROP ratios, which suggests that a moderately good relationship exists between these two measures of the suprathreshold. DiCarlo and Powers (1998) also reported that paper tests and magnitude matching yielded the same classifications for 84% of participants, although only twenty-two individuals were studied.

1.11 Psychophysical Procedures Selected for Use in Thesis

Literature from the past seven decades has been reviewed in order to evaluate the main methods used to determine taster status and to select the best. Future laboratory based studies will measure both absolute thresholds and suprathreshold responses since they seem to measure different aspects of taste. The modified staircase method appears to be the best available method of determining the former since it is the most refined alternative and deals with the criterion problem. Magnitude matching will be used to determine suprathreshold responses since it is necessary to employ a standard to enable comparisons across individuals and between (PROP taster) groups. Magnitude estimation will also be used to measure suprathreshold responses as it yields ratio level data (which category scales do not), and has been refined by implementing minor procedural changes to counter previous weaknesses (needed by the LMS).

Chapter Two

Review of Background Literature

2.1 The Genetics of Taste

Almost since the discovery of taste blindness, it has been established that perception of the taste of PTC/PROP is a heritable trait. Studies that examined PTC thresholds in parents and their offspring consistently reported that, practically all of the offspring of two non-taster parents are also non-tasters. Considerably higher proportions of offspring of two taster parents are tasters than offspring with one taster and one non-taster parent (Snyder, 1931; Snyder, 1932; Blakeslee and Salmon, 1931; Blakeslee, 1932; Das, 1958; Olson et al., 1989). Intra-pair threshold differences and variances are significantly greater in dizygotic (non-identical) twin pairs than monozygotic (identical) twin pairs for PTC and PROP, again suggesting a strong genetic influence in PROP tasting ability (Martin, 1975; Krondl et al., 1983; Forrai and Bankovi, 1984; Kaplan et al., 1967).

Although it is generally accepted that PROP perception is genetically determined, there is still debate as to the exact mode of inheritance. The tendency for distributions of PTC thresholds to be roughly bimodal was thought to suggest that taste sensitivity followed a simple Mendelian pattern. Those with low taste thresholds above the antimode (tasters) were thought to be homozygous or heterozygous dominant (TT or Tt) and with thresholds below the antimode (non-tasters) were thought to be homozygous recessive tasters (tt). The earliest of the family studies (Snyder, 1931; Blakeslee and Salmon, 1931; Blakeslee, 1932) found that offspring of two non-taster parents were *all* non-tasters, supporting the idea that taste deficiency is inherited through a single genetic locus as an autosomal recessive trait. However these studies used the crystal or serial dilutions methods for PTC testing which are quite crude measures. The later studies which used more refined methods such as that of Harris and Kalmus (1949), found taster offspring from non-taster parents, (Das, 1958; Olson et al., 1989). Studies with sibling pairs also failed to provide support for a Mendelian model (Harris and Kalmus, 1951; Das, 1956). These reports led to the proposal of alternative models of inheritance.

Kalmus (1958) proposed an additive rather than a dominant model. He reported that incomplete dominance of the T allele results in homozygous tasters being more sensitive to PTC than heterozygous tasters. Reed et al. (1995) using maximum likelihood estimations found that the genetic model with the greatest likelihood had three distributions and followed an additive model of taste sensitivity. Ellerd (1998) reported a heritability of taster phenotype of approximately 0.50 (i.e. 50% of variability could be explained by heredity). She also concluded that this suggests that inheritance of taster phenotype is more complex than that of a single dominant gene.

Whether a second locus or a third allele controlling *general* taste sensitivity is involved has also been considered. Olson et al. (1989) found that two-locus and one-locus three-allele models explained the inheritance of PTC tasting better than the traditional one-locus recessive model. They suggested that there are two types of non-tasters: those with a specific PTC taste deficiency, and those with a more general taste deficiency. Supporting evidence comes from Frank and Korchmar (1985) and Kalmus (1958). Kalmus found that tasters and some non-tasters showed the same sensitivity to quinine whereas other non-tasters were insensitive to quinine. Frank and Korchmar studied tasters' and non-tasters' sensitivity to PTC as well as their reaction times in judging the intensity of sucrose, NaCl, HCl and quinine sulphate. Reaction times were used as a measure of differences in gustatory processing. Three types of participants emerged: tasters who had high sensitivity to PTC and fast reaction times; "sensitive non-tasters" with low sensitivity to PTC and equally fast reaction times; and "less sensitive non-tasters" with low sensitivity to PTC and significantly slower reaction times. The authors concluded that two groups of non-tasters exist, both having a specific taste deficit involving PTC, but only one with a general taste deficit. However Rao and Morton (1977) found no evidence for either incomplete dominance or polygenetic variation. However, they acknowledged that a larger sample, a different population, or use of the complete sorting test (they did not use the full range of solutions) might give evidence of inheritance not due to a completely recessive gene.

The debate as to the exact mode of inheritance will not be concluded until the relevant gene or genes have been identified. A locus for PTC tasting was reported near the Kell blood group locus (7q31) on chromosome seven (Chautard-Friere-Maia, 1974; Conneally et al., 1976), although this finding could not be replicated (Spence et al., 1984). Reed et al. (1999a, 1999b) found evidence for a major locus on chromosome five (5p15) and for an additional locus on chromosome seven. Since a cluster of four taste receptors were localised near the Kell locus (T2R3, T2R4, T2R5, T2R16) and another receptor (T2R1) within the area of 5p15 (Adler et al., 2000), they were identified as candidates for the PTC/PROP gene. Reed et al.'s (2001a) genetic mapping did not rule out T2R1 as a PTC/PROP gene, although they thought a more likely candidate would be a centromeric gene (near the "waist" of the chromosome) or a gene cluster. Linkage was not demonstrated between the taste cluster and PROP intensity ratings, although there was a slight but non-significant trend for linkage when participants were divided into tasters and non-tasters when a variety of dominant, additive, and recessive models were tested (Reed et al., 2001b). Reed's research team concluded that if the genes for the cluster of taste receptors on chromosome seven were involved in the perception of PTC and PROP, they could be more important for threshold detection than suprathreshold intensity ratings, and account for less variance than the locus on chromosome five (Guo and Reed, 2001).

2.2 Food Rejection Theory

Genetic transmission of the taster phenotype may have evolutionary advantages. According to the food rejection theory many wild plants and vegetables containing various bitter tasting N-C=S compounds found in PROP and PTC also contain toxic elements. Their bitter taste may lead tasters to avoid eating these plants and thus avoid their harmful effects. This is supported by the lower numbers of non-tasters reported among tribal people than amongst populations with a long history of urban life (Kalmus, 1971). The disappearance of such plant foods from the diet of the latter group may have relaxed the selection against the non-tasting genotype.

A second functional explanation of the existence of genetically mediated taste sensitivity to PTC and PROP suggests that high sensitivity to the H-N-C=S component protects against goitre. This is a condition caused by iodine deficiency where the thyroid gland is enlarged, making the anterior portion of the neck appear swollen. Goitrin and isothiocyanates are bitter PTC/PROP related compounds that result from the hydrolysis of glucosinolates found in cruciferous vegetables (Jerzsa-Latta, Krondl and Coleman, 1990). Consumption of these vegetables has been associated with a significant decline in iodine uptake by the thyroid (Langer and Kutka, 1964) and with higher prevalence of endemic goitre (Hetzel, 1993). Tasters' heightened perception of the bitter taste of these vegetables may make them more likely to reject them and reduce the risk of developing this condition.

Just as urbanisation limited exposure to toxic plants, the introduction of iodised salt has decreased the risk of iodine deficiency, thus making both these protective functions largely redundant in modern day urban societies.

2.3 Anatomical Studies

The taster genotype may express itself through anatomical differences in taste receptors. The perceived bitterness of PROP correlates significantly with density of fungiform papillae and taste pores (Bartoshuk et al., 1994; Cohen et al., 1999; Reedy et al., 1993; Tepper and Nurse, 1997a; Tepper and Nurse, 1997b). Supertasters have the most taste pores and the highest numbers of fungiform papillae that are smaller and contain more taste buds that are surrounded by ring-like structures not found on non-tasters' fungiform papillae (Reedy et al., 1993; Cohen et al., 1999). These ring-like structures would appear to be trigeminal fibres since Whitehead et al. (1985) has shown that these neurons surround taste buds in hamsters. The trigeminal (V^{th} cranial) nerve transmits information about oral burn and oral touch (Silver and Finger, 1991).

2.4 PROP Tasting and Taste Acuity for Other Substances

The fact that supertasters have the most taste receptors and trigeminal innervation suggests that they may show heightened perception of tastes in foods. Some (but not all) bitter foods are chemically related to PROP since they contain the H-N-C=S molecule grouping. There has also been study of PTC/PROP tasting ability and acuity for sweet and fat as well as substances that cause oral irritation.

2.4.1 Bitter

2.4.1.1 Fruit and Vegetables

Vegetables in the cruciferae family contain goitrin and isothiocyanates which contain the same H-N-C=S component found in PTC and PROP, thought to be responsible for their bitter taste. Cruciferous vegetables include broccoli, Brussels sprouts, cabbage, cauliflower, collard, kale, kohlrabi, radishes, white turnips, and watercress. Some non-cruciferous vegetables (e.g. spinach and endive) taste bitter although this is caused by components other than the H-N-C=S grouping (Jerzsa-Latta et al., 1990). Flavanoids are the cause of the bitter taste of many citrus fruits. The bitter taste of grapefruit is attributed to the flavanoid naringin. There are inconsistencies in the literature as to whether acuity for the bitter tastes of these fruits and vegetables varies with taster status.

Cubero-Castillo and Noble (2000) found a significant correlation between PROP taster status and naringin thresholds, but not intensity ratings. Drewnowski, Henderson, and Shore (1997a) also found no PROP effect for intensity ratings of naringin solutions whereas a French study found that non-tasters perceived a significantly *more* bitter taste from naringin solutions than tasters (Smagghe and Louis-Sylvestre, 1998). The authors attributed this unexpected finding to the fact that the naringin was dissolved in a sucrose solution. Since the tasters were found to like sucrose, they may have found them less distasteful and therefore rated the naringin solutions as less bitter than the non-tasters. However, Drewnowski et al.'s and Smagghe and Louis-Sylvestre's results may be attributable to methodological flaws. When measuring the PROP threshold, Smagghe and Louis-Sylvestre decreased the stimulus concentration after one correct response rather than two which can generate incorrect thresholds. The threshold distribution had a false antimode at a concentration that was in the taster range. Both studies used a category scale to measure PROP suprathreshold responses which can produce ceiling effects. Investigating grapefruit juice rather than naringin solutions, individuals with heightened PROP perception gave the highest bitterness ratings, though it was unclear whether grapefruit juice was tasted or recalled from memory (Duffy et al., 2001).

Several studies did not find a relationship between taster status and bitterness of vegetables. Mattes and Labov's (1989) study of 282 non-smoking college students failed to find an association between PTC taster status and bitterness ratings of a variety of foods including cruciferous and non-cruciferous vegetables and fruit (including grapefruit). Similarly, Jerzsa-Latta, Krondl, and Coleman (1990) found no effects of PTC taster status on bitterness ratings of cooked and raw cruciferous vegetables, and bitter tasting non-cruciferous vegetables (spinach and endive). Whereas the two former studies examined self-reported bitterness ratings on questionnaires, Niewind, Krondl, and Shrott (1988) employed actual tasting. They studied older adults ranging in age from fifty-five to seventy years (mean age: sixty-three years). They reported that tasters and non-tasters did not differ in their ratings of the bitterness of both raw and cooked cabbage, although the tasters rated cooked cabbage as having significantly more flavour than the non-tasters did. Although Mattes and Labov employed a category scale to measure PROP acuity, which as previously mentioned is liable to ceiling effects and can diminish or wipe out PROP effects, the latter two studies did not.

With the exception of Drewnowski, Henderson and Shore (1997a) and Louis and Sylvestre (1998), all of the cited studies were carried out prior to 1992 when the first functional separation of tasters into medium tasters and supertasters was achieved (Bartoshuk et al., 1992). One possibility that has not been explored is that participants' intensity ratings may be based on their hedonic rather than their sensory responses. It is possible that two individuals (or two PROP taster groups) may perceive an equally bitter taste, but one as less pleasant and adjust the intensity rating accordingly.

2.4.1.2 Caffeine

Coffee contains several bitter constituents, one of which is caffeine. Hall et al. (1975) found that caffeine thresholds, like those of the phenothioureas, are bimodally distributed, with one group showing low sensitivity to the taste of caffeine and the other displaying high sensitivity. They also found a significant correlation between PTC and caffeine thresholds. However when Hall et al. examined the psychometric function of *suprathreshold* concentrations of caffeine they found that a difference between tasters and non-tasters magnitude estimations existed only at the lower concentrations. Cubero-Castillo and Noble (2000) also found a significant correlation between PROP taster status and caffeine thresholds, but not for PROP intensity ratings.

Ly and Drewnowski (2001) found that PROP tasters rated caffeine as significantly more bitter than did non-tasters. The addition of the sweetener neohesperidin dihydrochalcone to caffeine solutions suppressed bitterness intensity more effectively for tasters than non-tasters (whose ratings were already at baseline), although tasters still perceived sweetened caffeine solutions as more bitter.

Neely and Borg (1999) looked at the duration and intensity of caffeine aftertaste using a time-intensity procedure. The caffeine aftertaste of a saturated caffeine solution (0.056 M) diminished quicker in non-tasters than tasters, but after four minutes both the tasters' and non-tasters' mean ratings began to level out. In a second experiment examining intensity of aftertaste, both groups' initial ratings of a saturated caffeine solution began at the same level, but the non-tasters' intensity ratings decreased faster with time. Non-tasters' aftertaste ratings of a weaker caffeine solution (0.018 M) were lower throughout the whole time period. Although Neely and Borg's study provides an original approach that complements existing PROP taste sensitivity work, it has several methodological weaknesses. Supertasters were not differentiated even though the concepts and methods of doing so were available at the time. Only a small number of participants were studied (N = 7 to examine length of caffeine aftertaste, and N = 18 to look at intensity), although this was intended only as a preliminary investigation, to see if further detailed study would be warranted.

Several studies have not found an association between acuity for PROP and caffeine (Leach and Noble, 1986; Mela, 1989; Smagghe and Louis-Sylvestre, 1998). The difference in findings may be attributed to procedural differences. Whereas Hall et al. presented the caffeine at 34°C using the flow method (solutions flowed onto the tongue through a McBurney gravity flow system; McBurney and Pfaffmann, 1963), these other researchers presented the stimuli at room temperature using a sip-and-spit procedure. Bartoshuk et al. (1982) found that sucrose tasted less sweet to both tasters and non-tasters at room temperature than at 34°C - perhaps the same phenomenon can be extended to the bitterness of caffeine. Leach and Noble used a very small sample (8 tasters, 6 non-tasters) and tested a more limited concentration range. Although Smagghe and Louis-Sylvestre (1998) also found that tasters' and non-tasters' intensity ratings of caffeine did not differ, they did find a significant difference for the solution of caffeine in the middle of the range of five concentrations, which corresponded to the concentration found in brewed coffee. However, as noted previously, Smagghe and Louis-Sylvestre failed to use a Wetherill and Levitt modification when measuring PROP thresholds and also used a category scale to measure suprathreshold ratings which affected classification of taster groups and reduced the chance of identifying PROP effects.

Few studies have examined the relationship between PTC/PROP taster status and the intensity of caffeine used tasting actual foods or drinks that contain caffeine, and it is uncertain whether these findings with laboratory preparations extend to real foods with more complex tastes. Duffy et al. (2001) found that increased PROP perception was associated with increased perception of bitterness from coffee, though it is unclear if ratings were based on tasting or memory recall.

2.4.1.3 Soy Products/Green Tea

Green tea contains polyphenols and flavanoids which contribute to its bitter taste. Soy products contain also contain flavanoids as well as isoflavones. Bitter flavanoids are thought to be beneficial in the prevention and control of cancer. Heightened sensitivity to PROP was related to greater perceived bitterness of green tea, but not in plain and vanilla flavoured soymilk, miso, or plain tofu (Akella, Henderson, and Drewnowski, 1997). Again a category scale was used which can create ceiling effects and eliminate/diminish PROP effects.

2.4.1.4 Sodium Benzoate/ Potassium and Sodium Chloride

Sodium benzoate (C_6H_5COONa) is a preservative which is added to soft drinks whilst potassium chloride (KCl) is used as a substitute for common salt (sodium chloride/ NaCl) by individuals on a low sodium diet. All are chemically unrelated to PTC and PROP. Bartoshuk et al. (1988) examined the effect of PROP taster status on perception of aqueous solutions of NaCl, KCl, and sodium benzoate. They found that tasters rated the bitterness of these substances as being stronger than did non-tasters. However this result for NaCl is inconsistent with other reports that there is no association between PROP perception and the perceived intensity of sodium chloride (Jefferson and Erdman, 1970; Bartoshuk, 1979; Bartoshuk, Duffy, and Miller, 1994; Marks et al., 1988; Mela, 1989, 1990; Sato et al., 1997). Yackinous and Guinard (2001) examined perception of saltiness in real foods (potato chips and mashed potatoes) rather than NaCl solutions, and similarly reported no effect of PROP tasting ability. Schifferstein and Frijters (1991) found that intensity ratings of KCl as well as NaCl were unrelated to taster status. They suggested that Bartoshuk et al.'s finding that tasters perceived more bitterness from NaCl than non-tasters could be attributed to a response effect rather than a sensory effect. The tasters may have tended to give higher magnitude estimates than non-tasters when rating bitterness. This argument is supported by the fact that tasters' magnitude estimates of water were (although not significantly) higher than non-tasters', although the same research team later replicated the finding that NaCl perception increased with PROP perception (Bartoshuk et al., 1998).

Tuorila et al. (1997) examined the effect of partially substituting KCl for NaCl in cream cheese on sensory ratings according to PROP tasting ability. "High tasters" (equivalent to supertasters) gave higher bitterness ratings to the low fat cream cheese (10% fat) samples, but the lowest bitterness rating to the high fat sample (40% fat). They suggested that the latter finding could be attributed to a suppressing effect of fat on perceived taste intensity in tasters compared to non-tasters. Saltiness ratings decreased with increasing KCl content particularly among those most sensitive to PROP.

2.4.1.5 Dairy Products

Marino et al. (1991) reported that some tasters found calcium chloride (found in cheeses and dry milk powder) and casein (a protein found in milk) to taste more bitter than did non-tasters. Since protein molecules are too large to stimulate taste, Marino et al. suggested that the bitter taste comes from amino acids. They also asked adults to taste several cheeses (Montery jack, American, mild cheddar, sharp cheddar, Brie, mozzarella, Swiss Muenster, and blue) and to rate their bitterness, sweetness, saltiness, sourness, and creaminess. Tasters and non-tasters' ratings of sweetness, sourness and creaminess did not differ significantly. However tasters rated two of the eight cheeses (sharp cheddar and the Swiss cheese) and dry milk powder to taste more bitter than the non-tasters did. Tasters also rated American and cottage cheese as being more salty than non-tasters.

2.4.2 Sweet

Sweet substances such as sucrose and saccharin do not contain the bitter H-N-C=S molecule grouping found in phenylthioureas. Although these substances taste sweet, some (e.g. saccharin) also taste bitter. The literature examiningthe relationship between PROP/PTC taster status and intensity for sweet substances is extremely inconsistent.

Bartoshuk (1979) found that tasters rated sucrose and saccharin solutions as tasting sweeter, and saccharin as more bitter, than non-tasters. However these differences between the taster groups were only observed at the lowest concentrations. Gent and Bartoshuk (1983) carried out three replications of Bartoshuk's (1979) study, each experiment using a slightly different variant of her original method. Neohesperidin dihydrochalcone (DHC) was also added to the test compounds. Sucrose, saccharin and DHC tasted significantly sweeter to tasters than to non-tasters when these solutions were delivered via the flow system rather than using the sip-and-spit procedure. When their intensity was rated against tones instead of NaCl, again using the flow method of delivery, only sucrose and DHC were significantly sweeter to tasters than to non-tasters. These differences were also significant but a lot smaller when the sip-and-spit technique was employed. This was attributed to the fact that the stimuli in the flow method were delivered at a higher temperature (34°C) than in the sip-and-spit procedure (20°C), since sucrose has been found to taste less sweet to both tasters and non-tasters at 20°C than at 34°C (Bartoshuk et al., 1982).

The relationship between PROP tasting ability and acuity for sweetness was studied further using techniques to differentiate the taster group into medium tasters and supertasters. Drewnowski, Henderson and Shore's (1997b) female sample tasted and rated the intensity of sucrose and saccharin solutions. PROP taster status was not related to perceived sweetness of sucrose although, consistent with Bartoshuk (1979), non-tasters perceived the lowest concentration of sucrose (2% w/v) as less sweet than medium tasters or supertasters. Sweetness and bitterness intensity ratings of saccharin were also independent of PROP taster status. Drewnowski, Henderson, Shore, and

Barratt-Fornell (1997) replicated the finding that genetic sensitivity to PROP was unrelated to sweetness intensity ratings of sucrose solutions. However these three studies used a nine-point category scale to measure intensity ratings.

Work which separated medium tasters and supertasters and also avoided scales that introduce ceiling effects tended to identify PROP effects on perception of sweetness. Lucchina et al. (1998a) obtained sweetness intensity ratings for sucrose and a variety of sweeteners: alitame, aspartame, DHC, saccharin, and polyols, (xylitol, sorbitol, maltitol, lactitol). Heightened PROP perception was associated with higher sweetness ratings of sucrose and the sweeteners with the exception of the polyols. This PROP effect was most evident in women. Ko et al. (2000) reported that supertasters rated the intensity of three strongest sucrose solutions as more intense than non-tasters, but ratings converged for the weakest solution. A Japanese study also observed a PROP effect for sucrose (Sakai and Imada, 2000). Bartoshuk et al. (1992) found that supertasters perceived much greater intensities for (unspecified bitter and) sweet stimuli than medium tasters and supertasters. They later asserted that sucrose tastes approximately 50% sweeter to the average supertaster than to the average non-taster (Bartoshuk et al., 1999b).

The above studies measured responses to sweet solutions which are not representative of real foods and beverages in which interactions of different components create more complex tastes. Prescott and Ripandelli (2000) looked at taste mixture interactions as a function of PROP taster status. Participants tasted combinations of sucrose with quinine hydrochloride (QHCl; sweet-bitter) and sucrose with citric acid (sweet-sour). There were no significant differences between taster groups in their ratings of sweetness, bitterness, or sourness alone, or the sweet-sour mixtures. However, 0.036 mM QHCl suppressed the perception of sweetness in the sucrose-QHCl mixture for medium tasters and supertasters but not among non-tasters. Supertasters also showed a greater influence of QHCl in determining the overall intensity of the sweet-bitter mixtures.

The only way to find out if heightened PROP perception is associated with increased acuity for sweetness in complex foods and drinks is to directly examine real foods. One recent study examined intensity ratings of a list of an unspecified number of sweet foods on a questionnaire and sweet foods that were tasted: three candies, cake, icing, and jellies (Peterson and Duffy, 2000). Those who found PROP to taste most intense gave the highest average sweetness ratings to five (unspecified) foods. Sweetness and bitterness intensity ratings of chocolate and sweetness ratings of chocolate drinks and vanilla puddings were similar for tasters and non-tasters (Ly and Drewnowski, 2001; Yackinous and Guinard, 2001).

2.4.3 Fat

It is commonly believed that fat is perceived by its texture rather than by taste or olfaction. For example Bartoshuk et al. (1999a) argued that fat molecules are too large to stimulate taste or smell but do create tactile sensations such as oiliness or creaminess. However, Gilbertson et al. (1997) produced physiological evidence for the perception of a taste in fat. Isolated rat fungiform taste buds were directly stimulated by polyunsaturated free fatty acids (both contained in fat and generated via the action of lipase in the oral cavity after ingestion). Despite this, the prevailing idea is still that fat is predominantly perceived by textural rather than chemosensory cues.

Several recent studies have examined non-tasters', medium tasters' and supertasters' textural perception of fat. Since the perception of texture is partially mediated by trigeminal fibres, and supertasters have more trigeminal innervation, Tepper and Nurse (Tepper and Nurse 1997a; Tepper and Nurse, 1997b) speculated that fat perception might be linked to taster status and taste bud density. As predicted, medium tasters and supertasters could discriminate between salad dressings containing 40% and 10% fat, but the non-tasters could not. However, there was no difference between medium tasters and supertasters discriminations. Duffy et al. (1996) examined creaminess ratings of milk products with varying fat content (0.5 to 54% fat). Creaminess ratings of products containing 11.5%, 36%, and 54% fat, were significantly higher among supertasters than medium tasters or non-tasters, but not among the stimuli that were lower in fat content. Prescott et al. (2001) similarly found that supertasters gave higher creaminess ratings, particularly at higher fat levels. There is also evidence that perception of corn oil and guar gum (a thickening agent) increases with PROP tasting ability (Prutkin, unpublished thesis, cited in Prutkin et al., 2000; Prutkin et al., 1999a). Yackinous and Guinard (2001) however found that PROP tasting ability did not influence fattiness ratings of mashed potatoes, potato chips, chocolate drinks, or vanilla puddings with variable levels of fat and flavouring (butter, sour cream and onion, cocoa, and dairy flavourings respectively), except in the case of the high fat/low flavour mashed potato sample where medium tasters gave the highest fattiness scores.

2.4.4 Sweet/Fat

Drewnowski, Henderson, and Barratt-Fornell (1998) examined the relationship between PROP taster status and response to sugar/fat mixtures in actual foods and beverages. The stimuli were milk (3.5% fat), "half-and-half" (10.5% fat), and heavy cream (30% fat), each sweetened with 2%, 4%, 8%, 16% and 32% sucrose. Participants rated the sweetness, creaminess, and fat content of each of the fifteen stimuli and gave hedonic ratings. Sweetness and creaminess ratings, as well as the perceived fat content of the sugar/fat mixtures, were independent of PROP taster status. Tepper (1998) suggested that the failure to show the expected pattern of responding in Drewnowski et al.'s study could be due to masking, the phenomenon where adding sweetness to fat tends to mask the perception of fat (Drewnowski and Schwartz, 1990). She argued that since masking reflects integration of signals at higher brain centres, it is probably unrelated to taster status. However it could also be due to the use of a category scale to measure PROP intensity.

2.4.5 Oral Irritation

Oral irritants in food include capsaicin (chilli peppers), piperine (black pepper), zingerone (ginger), ethanol (alcoholic drinks), cinnamaldehyde (cinnamon), and menthol (Bartoshuk et al., 1994; Prescott and Swain-Campbell, 2000). The irritation caused by these compounds is characterised by oral burn and/or oral pain. Although there are numerous studies of the relationship between PROP tasting and irritation caused by capsaicin and ethanol, there has been only one study of cinnamaldehyde and no study to date of the other oral irritants.

2.4.5.1 Cinnamaldehyde

The only study of the oral irritation of cinnamaldehyde found that a combined group of medium tasters and supertasters (due to small sample size: N = 32) rated the irritation of cinnamaldehyde as significantly more intense than did non-tasters (Prescott and Swain-Campbell, 2000).

2.4.5.2 Capsaicin

Capsaicin is found in high concentrations in fruit of plants of the capsicum genus such as chilli peppers, red peppers and in paprika. This substance is primarily responsible for the oral burn and irritation that is experienced when chilli peppers are consumed.

Karrer and Bartoshuk (1991) hypothesised that since PROP tasters have the most taste buds, and that taste buds in the fungiform papillae are surrounded by trigeminal neurons believed to innervate oral burn receptors, tasters should be more sensitive than non-tasters to the burn of capsaicin. Consistent with this hypothesis, they found that PROP tasters rated the perceived burn of capsaicin higher than non-tasters. However, McBurney et al. (2001) found that PROP tasting did not affect magnitude estimates of capsaicin, although tasters gave significantly higher ratings to the higher capsaicin concentrations. These two studies did not separate medium tasters and supertasters. Studies that did found that supertasters rated the burn of capsaicin as more intense than did non-tasters (Karrer et al., 1992; Bartoshuk et al., 1996a; Tepper and Nurse, 1997a;

Tie et al., 1999; Prescott and Swain-Campbell, 2000). Capsaicin solutions, or in one case "capsaicin candy" or "taffy" (Bartoshuk et al., 1996a) were used rather than chilli peppers. This allowed control of the amount delivered, but studies with actual chilli peppers would complement the existing literature, and allow greater generalisation to real foods.

2.4.5.3 Ethanol

Oral properties of ethanol (also referred to as ethyl alcohol) include bitterness as well as irritation. Other bittering agents in beer are isomerised forms of certain hop resin components, particularly the iso-alpha-acids also known as isohumulones (Mela, 1990). Kajura et al. (1997) provided evidence suggesting that ethanol also contributes to the taste of beer, more so at room temperature than at 8°C.

Ethanol (10%) tasted more bitter and felt more irritating to supertasters and medium tasters than to non-tasters when applied to the tip of the tongue (Bartoshuk et al., 1993). When 10-50% solutions were tasted in the whole mouth, all concentrations were perceived by medium tasters and supertasters to be more bitter and 30-50% solutions as more irritating. Prescott and Swain-Campbell (2000) also found that PROP tasters (medium tasters and supertasters combined) rated the irritation of 47.5% ethanol as more intense than non-tasters. Supertasters also rated the bitterness of 50% ethanol as more intense, disliked it more, and reported drinking significantly less alcohol than non-tasters (Duffy and Peterson, 2000). However, Mattes and DiMeglio (2001) found that PTC tasters and non-tasters did not differ in their ethanol taste and irritation thresholds, as well as in their suprathreshold intensity and quality ratings of both ethanol and tetralone (iso-alpha-acids).

It cannot be assumed that responses to a substance in solution will be the same when in more complex alcoholic drinks. Mela (1990) found that suprathreshold concentrations of isohumulones in water, but not in beer, were perceived as more intense by PROP tasters than non-tasters. This may be because other constituents in beer considerably modify the bitterness of isohumulones (Palamand and Aldenhoff, 1973).

Intranuovo and Powers (1998) studied commercial alcoholic drinks - Pilsner Urquell and Budweiser. Supertasters found the Pilsner significantly more bitter than medium tasters and non-tasters. There were no differences for Budweiser, rated as significantly less bitter than Pilsner by all three groups. Male supertasters gave significantly lower hedonic ratings to the Pilsner than medium tasters and non-tasters, but only when Budweiser was tasted first. Supertasters reported consuming significantly less beer when they first started drinking beer on a regular basis, but there were no significant differences in current drinking behaviour. The difference between initial and current drinking patterns was interpreted as evidence that multiple factors contribute to drinking behaviour. Intranuovo and Powers concluded that supertasters may be protected against alcoholism for three reasons: they find a bitter beer more bitter; they like a bitter beer less; they drink less beer initially than non-tasters.

2.5 PROP Tasting and Alcoholism

There is some evidence to suggest that sensitivity to PROP/PTC is related to alcoholism, although these findings have not been replicated.

Several studies examined difference in tasting ability between alcoholics and non-alcoholics. Whereas two unpublished theses (Peeples, 1962; Spiegel, 1972; as cited in Pelchat and Danowski, 1992) found that alcoholics were more likely to be non-tasters than controls, other studies (Reid et al., 1968; Smith, 1972; Swinson, 1973) failed to find a difference in taster status. Variations in sample characteristics may account for these inconsistencies. Reid et al.'s participants were hospital patients being treated for cirrhosis of the liver, alcoholism being the causative factor in most (84%) but not all cases. Their control group, as well as including some hospital employees, also included non-cirrhotic patients. These individuals may have suffered head trauma, had x-rays or ear-infections which are reported to alter the sense of taste (Bartoshuk et al., 1996b; Kalmus and Farnsworth, 1959). Although Swinson (1973) observed that alcoholics tended to be concentrated towards the less sensitive end of the distribution of thresholds, he found no difference in taster status between alcoholics and non-alcoholics. The controls were a lot younger than the alcoholic group (mean age = 21.2 as compared to 43.2) and were predominantly female, whereas the alcoholic group was predominantly male. However, younger and female adults tend to have heightened PTC/PROP perception, so these differences between the alcoholic and control groups could potentially *increase* the difference in taste perception rather than account for their similarity.

Studies of the relationship between taster status and alcoholism did not examine the direction of effect. Excessive alcohol consumption may have made individuals less sensitive to the bitterness of alcohol either through adaptation or damage to taste buds. Since there is evidence for a genetic contribution to the development of alcoholism (Kranzler, Skipsey, and Modesto-Lowe, 1998), this issue has been addressed by subsequent studies that determined the PROP taster status of offspring of alcoholics and non-alcoholics.

Pelchat and Danowski (1992) and DiCarlo and Powers (1998) reported that there was a higher proportion of non-tasters among children of alcoholics than children of non-alcoholics. This suggested that taster status influences alcoholism status rather than vice versa. However, other studies did not support these results. Mattes and DiMeglio (2001) reported that tasters and non-tasters did not differ in the prevalence of family history of alcoholism. Kranzler, Moore, and Hesselbrock (1996) attempted to replicate Pelchat and Danowski's work using interviews with fathers to assess paternal alcoholism status rather than questionnaires completed by the offspring. They found no association between the ability to taste PROP and paternal alcoholism. However, whereas Kranzler et al. excluded individuals with a maternal history of alcoholism, thirty percent of children with alcoholic parentage in Pelchat and Danowski's sample had two alcoholic parents. Having two rather than one alcoholic parent has been shown to be associated with earlier onset of alcoholism and a more severe course (Hesselbrock et al., 1982; Volicer et al., 1983).

Kranzler, Skipsey and Modesto-Lowe (1998) conducted further investigations to see if this discrepancy in findings could be attributable to differences in parental history of alcoholism. Maternal, paternal, and bilineal history of alcoholism did not affect taster status either individually or when grouped together. All potential confounding variables (gender, smoking status, Antisocial Personality Disorder) did not significantly influence taster status. Kranzler et al. (1998) studied only alcoholic offspring whereas Kranzler et al. (1996) studied only non-alcoholic children, and Pelchat and Danowski a mixture of alcoholic (45%) and non-alcoholic (55%) offspring. Kranzler et al. (1998) argued that if his two samples were taken together they represent Pelchat and Danowski's sample.

The studies that looked at familial history of alcohol dependence also investigated PROP tasting ability and alcoholism in the offspring. Three of the four studies showed that there was no association between the children's PROP tasting ability and diagnosis of alcohol dependence (Pelchat and Danowski, 1992; Kranzler et al., 1998) or alcohol risk (Kranzler et al., 1996). However, DiCarlo and Powers (1998) found that alcoholic offspring were more likely to be non-tasters than non-alcoholic offspring. DiCarlo and Powers suggested this discrepancy in findings may be attributed to the fact that more of their alcoholic participants had alcoholic parents, and that Pelchat and Danowski's sample were younger (18-29, mean age not available, as compared to 18-57, mean age: 29) and many had not finished their twenties, the period of greatest risk from alcoholism (Merikangas, 1990). Although Kranzler et al. (1996) also studied a younger sample (14-21), Kranzler et al.'s (1998) participants were comparable in age to DiCarlo and Power's (25-59) but did not find that alcoholic and non-alcoholic offspring differed in PROP tasting ability. DiCarlo and Powers also found that individuals with both alcoholism and depression in their family were more likely to be *supertasters*. This is inconsistent with the possibility that non-tasting may be a contributing factor to the risk of developing alcoholism. They suggested that PROP taster status might be a genetic marker for two types of alcoholism.

2.6 PROP Tasting and Smoking

Perception of PTC/PROP may influence acceptability of cigarettes as well as alcohol. When a cigarette is smoked several bitter tasting substances dissolve in the saliva and are tasted. These compounds include eighteen alkaloids including nicotine, twelve pyrrole and pyridine type nitrogenous bases, and fifteen amines (Fischer, Griffin, and Kaplan, 1963). As well as contributing to the bitter taste of cigarettes, nicotine is also an oral irritant. Two issues have been addressed: 1) whether genetic taste sensitivity to PTC/PROP influences acceptability of the taste of cigarettes and smoker/non-smoker status, and 2) if smoking affects ability to perceive phenylthioureas (I.e. PROP and PTC).

Data collected in the 1930s revealed no relationship between smoking and sensitivity to PTC (Salmon and Blakeslee, 1935; Falconer, 1947 using data collected by Professor R.A. Fisher between 1934 and 1939). However the early methodology used to measure thresholds was very unrefined. Both studies presented an ascending concentration series of PTC solutions, and separated tasters from non-tasters by plotting the frequency distribution of PTC thresholds, using the antimode as the cut-off point. Neither of the studies specified how the threshold was determined, or used an interstimulus rinse. It is most likely that the first solution that was thought to have a taste was taken as the threshold. In addition, both studies used a series of solutions where each solution was twice as concentrated as the preceding one. This rather large step between solutions may have led the thresholds to exceed their true values.

Krut, Perrin, and Bronte-Stewart (1961) and Koch and Nesarajah (1966) also reported no association between PTC taster status and smoking habits using an unrefined method of determining taster status. Both studies found similar proportions of tasters and non-tasters in smokers and non-smokers. Increasing concentrations of PTC solutions were presented, beginning with the most dilute. Whereas Koch and Nesarajah defined the threshold as the first solution to be perceived to have a taste, Krut et al. required that a taste must be perceived on two consecutive trials, the weaker of which was taken as the threshold. These methods are now considered to be an initial phase yielding an approximate threshold before a more accurate final threshold is determined.

Several studies have used a modified version of the Harris and Kalmus procedure to separate tasters and non-tasters. Smokers and non-smokers had similar PTC thresholds and frequencies of tasters and non-tasters in Spanish, Portuguese, Swedish and Brazilian samples (Pons, 1955; Akesson, 1959; Cunha and Abreu, 1956; Freire-Maia and Quelce-Salgado, 1960). Ellerd (unpublished data) found that smokers showed a trend for decreased sensitivities to PTC, but this difference was not significant. She attributed this to the small number of smokers (N = 42/1009) in this Mennonite sample, none of whom smoked more than ten cigarettes per day.

Although Fischer et al. (1963) reported no association between PROP taster status and smoking habits for all smokers (light and heavy) and heavy smokers, Kaplan et al. (1964) found significantly fewer tasters among heavy smokers than non-smokers. Individuals with greater taste sensitivity may be less likely to smoke because they are more sensitive to the bitter taste, assumed to be perceived as unpleasant. Kaplan et al. attributed the conflicting findings to the differing age groups of the two samples. Fischer et al.'s younger sample comprised mainly college students with less established smoking habits. The two studies also used different criteria to identify heavy smokers. Heavy smokers in Fischer et al.'s sample were defined as those who smoked fifteen or more cigarettes per day, whereas Kaplan et al.'s cut-off point was higher at twenty or more per day. This suggests that only very heavy smokers with established smoking habits are more likely to be less sensitive to the taste of PTC/PROP. The causal nature of this association is not apparent.

Thomas and Cohen (1960) found a PTC effect on smoking in a large sample of males (N = 829) but in the opposite direction to that reported by Kaplan et al. Smokers were significantly *more* sensitive to PTC than non-smokers. There were significantly more tasters than non-tasters among the smokers, and significantly more non-tasters than tasters among the non-smokers. Heavy smokers (20+ per day) showed a higher proportion of tasters than non-smokers in Caucasians but not among African-Americans. Non-smokers, light smokers, occasional smokers, and former smokers had comparable proportions of tasters. PTC tasting ability was measured using PTC impregnated filter paper. Participants were classified as tasters if they identified a bitter taste, and non-tasters if they reported no taste at all. However if a taste was perceived and given a label other than bitter (including sour), the individual was put in a "other" category. Use of this recognition rather than a detection procedure may have led to some misclassification since untrained assessors often are unable to consistently label samples representative of the four "basic" tastes: sweet, sour, salty, bitter (Wilton and Greenhoff, 1988).

No conclusive answer has been given to the question of whether PTC/PROP sensitivity is related to smoker status. Even if there were consistent evidence for an association, it would still remain to be established whether differential taste sensitivity affects smoker status, or if smoking diminishes taste perception. Several studies have examined the immediate effect of smoking on taste sensitivity in order to address this. Hall and Blakeslee (1945) found that smoking reduced the sensitivity to PTC in 73% of participants. Fifty-eight percent of the sample returned to their original threshold within an hour, whilst the remaining participants took several hours. However PTC sensitivity was measured in a similar way to that used by Salmon and Blakeslee (1935) and Falconer (1947) so the same procedural shortcomings may also have affected its accuracy. Freire-Maia (1960) employed the same procedure used by Hall and Blakeslee but used the Harris and Kalmus's standardised procedure to measure PTC sensitivity. Fifteen minutes after smoking, two participants' thresholds remained the same, one decreased and the other increased. A second experiment where thresholds were measured at several intervals before smoking rather than just once showed that variations after smoking were no different to those beforehand (N = 6). The small sample size clearly limits these findings.

Freeman et al. (2001) examined liking/disliking of the taste of cigarettes in sixteen and seventeen year old girls. PROP impregnated filter paper was rated on Green et al.'s (1993) Labelled Magnitude Scale. We found that supertasters liked the taste of cigarettes significantly less than the non-tasters. Previous studies did not investigate liking/disliking which may be a crucial and potentially mediating factor when assessing the association between PROP tasting and smoking habits.

It is evident that very little work in this area has been conducted in recent years. The implications of this are that more accurate methods of measuring PROP sensitivity are now available which also identify supertasters. Studies which examine both liking/disliking of the taste of cigarettes as well as smoker status/amount smoked using these methods would be especially useful. If PROP sensitivity does affect acceptability of cigarettes and smoking behaviour, PROP taster status could serve as a useful marker to identify high-risk individuals and to assist in the development of appropriate cessation strategies. For example, it is possible that a taste surrogate may be beneficial for non-tasters, but of less importance for supertasters.

2.7 The Effect of PROP Sensitivity on Body Mass Index (BMI)

Since PROP perception may influence the perception of fat, differential taste acuity may influence liking and intake of high fat foods. This in turn may affect amount of body fat. Or there could be a more direct genetic influence. The PROP tasting locus is reported to be near the KELL locus on chromosome seven which has been associated with the genetics of body weight in humans (Borecki et al., 1994). Weight relative to a "standard" can be compared across individuals of differing heights by calculating each person's body mass index (BMI; weight in kilograms, divided by height in metres squared: kg/m^2).

Reed et al. (1999b) found no relationship between PROP tasting ability and weight or BMI in a sample comprising both males and females. However when males and females are looked at separately a different trend emerges. Male supertasters and medium tasters have been reported to have slightly but not significantly lower body weights than non-taster males, with no relationship observed in women (Tepper, 1998; Tepper and Ullrich, unpublished data, reported in Tepper, 1998). Although Duffy and Bartoshuk (2000) found that perceived bitterness of PROP did not correlate significantly with BMI in both males and females, BMI increased with fungiform papillae density in men. Several other studies found that BMI was not related to PROP taster status in normal weight young women (Drewnowski, Henderson and Shore, 1997a, 1997b; Drewnowski, Henderson and Barratt-Fornell, 1998; Smaggheand Louis-Sylvestre, 1998; Kaminski et al., 2000; Ly and Drewnowski, 2001).

Associations between PROP bitterness ratings and BMI have been reported in middle-aged and older women. Dabrila, Duffy, and Bartoshuk (1995) found that fat intake and BMI decreased with increasing PROP bitterness in middle-aged women. PROP perception was negatively correlated with BMI, body fat and waist and hip circumferences in women ranging between sixty-five and ninety-five years of age (Lucchina et al., 1995; Lucchina, unpublished doctoral thesis, 1995). Although these associations were significant they were quite small (-0.23 to -0.30). The mean BMI was in the overweight range (27.97), higher than those in the studies which found no PROP effect on BMI in younger women.

Duffy et al. (1999) also reported different relationships between PROP intensity and body mass index in "normal" weight and overweight individuals. PROP bitterness ratings showed a negative relationship with BMI in the whole sample of males and females. This effect was strongest in normal weight individuals. Conversely, a positive association was observed in overweight/obese young adults. PROP perception was negatively correlated with liking of high fat foods in women, independent of the effects of age and BMI. In men, only age contributed to fat liking. These findings were also produced when data was collected from considerably larger data sets (Bartoshuk et al., 1999a, 1999b). Duffy and her colleagues concluded that the relationship between BMI and PROP may depend upon age, sex and degree of obesity.

Tepper and Ullrich (1999) hypothesised that dietary restraint may mask the association between PROP taster status and lower body weight in females. Among unrestrained eaters, supertasters had significantly lower BMIs than medium tasters and non-tasters. Also in keeping with the hypothesis, no relationship was observed between PROP taster status and BMI in restrained eaters. This suggests that an inverse relationship exists in both males and females but dietary restraint masks this relationship in women.

To conclude, it appears that many factors affect the relationship between PROP tasting and BMI: sex; age, degree of obesity, dietary restraint. Studies that did not find any PROP effect on BMI often did not take any of these factors into account. Differences in psychophysical methodologies in measuring PROP acuity may also have contributed to lack of association. Those studies that did find significant associations tended to measure bitterness ratings of suprathreshold PROP rather than PROP thresholds and used scales that do not produce ceiling effects.

2.8 Factors Affecting PROP Perception

PROP tasting ability may be affected by both innate and environmental factors. Variables that have been explored include age, sex, hormonal variations, pathology, and race.

2.8.1 Age

Whilst some studies have found that taste acuity declines with increasing age, others have failed to find any association.

Harris and Kalmus (1949) studied age effects in British males ranging in age from ten to ninety-one years. Sensitivity to PTC decreased with age, corresponding to half a dilution step per decade. This trend was observed for both tasters and non-tasters alike. One hundred and eight adults from the original sample were retested ten to fifteen years after initial testing (Kalmus, 1962), confirming the original finding. There was a mean annual increase in PTC threshold concentration of about 3% per year. Whissell-Buechy (1990) studied PTC sensitivity in three generations. They found that the difference in thresholds between generations amounted to seven or eight tenths of a dilution step. PTC sensitivity declined at an average rate of 0.027 dilution steps per year or 0.272 per decade, somewhat smaller than Harris and Kalmus's half a step per decade. However Whissell-Buechy sacrificed accuracy for speed when determining taster status. Participants were asked to identify the two samples out of five that they thought had a taste rather than four out of eight samples.

Several studies found that PTC/PROP taster status did not differ with age in adult samples. Reed et al. (1995) found that younger and older adults were equally able to detect PROP. Niewind, Krondl, and Shrott (1988) similarly concluded that the ability to taste PTC is independent of age amongst older adults ranging from fifty-five to seventy years of age.

Olfactory damage as well as anatomical changes to taste receptors may influence taste decrements with age. It has been established that age has an effect on retronasal olfaction (Bartoshuk et al., 1994). Hutchinson et al. (2001) examined anatomical differences in the tongues of young adult males and eight and nine-year-old boys. The children had more fungiform papillae that were smaller and more regularly shaped than those of the adults. They also had a greater density of taste pores on the tip of the tongue although the number of taste pores per papillae was similar in both adults and children.

2.8.2 Sex Differences

Results of studies examining the effect of sex on perception of PTC/PROP are more consistent than those examining age. Perception of PTC/PROP has been widely reported in the literature to be influenced by sex, with females showing greater acuity than males.

Sex differences in PTC/PROP tasting have been reported since the earliest studies dating back to the 1930s (Blakeslee and Salmon, 1931; Fernberger, 1932; Boyd and Boyd, 1937; Hartman, 1939; Falconer, 1947; Harris and Kalmus, 1949). These studies found women's thresholds to PTC to be significantly lower than those of males, indicating greater sensitivity among women than men. However, many of these pieces of research: used very primitive and unreliable methods of determining taster status; often studied very small and therefore unrepresentative samples; used PTC known to be detected by smell at higher concentrations; and preceded the advances that permitted the separation of medium tasters and supertasters. Bartoshuk, Duffy, and Miller (1994) also stated that the statistical tools used to analyse some of the early published data were not able to verify their findings. They examined the data from the earlier studies using modern statistical tests and reaffirmed their findings that the sex difference did indeed exist.

Bartoshuk et al. (1994) studied a large sample using a more rigorous method of determining taster status which permitted separation of the taster group, and the odourless PROP instead of PTC. They found that the distribution of taste thresholds for men and women were significantly different with the female distribution displaced toward the lower thresholds, a finding reported by many successive studies (e.g. Reed et al., 1995; Bartoshuk et al., 1996b; Whissell-Buechy, 1990; Ellerd, 1999). Bartoshuk and her colleagues also studied sex differences in taste anatomy. Females have more fungiform papillae and taste buds as well as the highest taste pore densities and variance in pores per papillae (Bartoshuk et al., 1994; Cohen et al., 1999). This may account for the finding that significantly more females than males were supertasters.

2.8.3 Hormonal Variations

Why females are more sensitive to the taste of PTC and PROP can be accounted for by a genetically transmitted evolutionary function. Duffy and Bartoshuk (1996a) suggested that women's heightened acuity to bitter tastes may be protective during pregnancy because naturally occurring bitter substances are often poisonous. The influence of hormonal variations on taste sensitivity has been examined during pregnancy, the menstrual cycle and menopause.

If heightened bitter perception serves to protect the unborn child, pregnant women should show increased acuity. Using a between groups approach, Bhatia and Puri (1991) compared women's taste sensitivity to PTC in each of the three trimesters. Those in their first trimester showed a higher frequency of tasters (86%) than those in their second (64%) or third trimesters (74%) as well as non-pregnant women (67%). Duffy et al. (1998) examined intensity ratings of bitter tasting quinine hydrochloride (QHCl) before becoming pregnant and at follow-up during the first, second, and third trimesters. A control group was followed up at equal intervals. Intensity ratings significantly increased from non-pregnant to the first trimester, the most crucial time of foetal development, and then decreased from the first to second and third trimesters. The control group showed significantly greater variance in intensity ratings than the pregnant women (also reported by Bartoshuk et al., 1997). This was attributed to the fact that the pregnant women's hormonal state was aligned whereas the control group were in different stages of their individual menstrual cycles.

The literature supports the idea that tasting ability varies during the menstrual cycle. Taste sensitivity to PROP and quinine significantly increased from pre-menstrual to menstrual phases and from menstrual to post-menstrual phases (Glanville and Kaplan, 1965b). Increased taste sensitivity to PTC and PROP has been found during the ovulation phase, a time of increased chance of conception, and the luteal phase, after ovulation when the uterine lining prepares for implantation of the early embryo (Bhatia et al., 1981; Etter, unpublished thesis, cited in Prutkin et al., 2000). Beiguelman(1964) however tested 100 women during menstruation and either fifteen days before or after and found no consistent effect of menstrual cycle on PTC threshold.

Bartoshuk et al. (1997) controlled for the effect of genetic sensitivity to PROP and produced evidence for menstrual control over perception of other oral sensations. Women showed higher variations than men in perception of sucrose, capsaicin burn, and the creaminess of fat, as well as taste bud number. Older post-menopausal women's perception of capsaicin burn did not vary more than men's. Bartoshuk et al. concluded from these findings that oral sensations vary in menstruating women and that this is mediated by variations in taste bud number.

Prutkin et al. (2000) elaborated on how this mediating mechanism might work. Again removing the influence of genetic variation, females showed significantly greater variance than men in number of fungiform papillae as well as taste pores. They proposed that it might be possible that the number of taste buds or access to them via open taste pores may vary across the menstrual cycle. This is not improbable since the average life of a taste receptor is ten days before it is replaced (Beidler and Smith, 1998) and the number of taste pores on individual papillae changes over time, sometimes by as much as 100% (Miller, 1987).

In addition to pregnancy and the menstrual cycle there is evidence that menopause also influences PROP sensitivity. Women in their sixties had significantly lower PROP bitterness ratings than women in their fifties (Prutkin et al., 2000). This corresponds with the fact that ninety percent of women have reached the menopause by age fifty-five (McKinlay et al., 1992). Since menopausal women are no longer in their child bearing years, the increased ability to detect poisons to protect the unborn child is no longer necessary.

2.8.4 Head injury/Ear Infections (Pathology)

Pathology may affect taste perception and thus PTC/PROP taster status. Alterations to taste function may result from otitis media (infection of the middle ear) and head injury due to damage to the chorda tympani nerve. This is a branch of the VIIth cranial nerve which travels from the tongue to the brain via the middle ear. It carries taste sensations from the fungiform papillae on the anterior two thirds of the tongue. Head injuries may cause lesions of the chorda tympani nerve, and viral or bacterial damage may occur with otitis media.

Bartoshuk et al. (1996b) reported that participants with a history of otitis media perceived significantly greater intensity from PROP and had significantly more taste pores per fungiform papillae on the anterior tongue than the control group. Damage localised to the chorda tympani nerve may result in intensification of bitter taste mediated by the glossopharyngeal nerve (Bartoshuk, 2000). Those with a previous head injury rated PROP as significantly less intense than individuals with no history of head injury. Although individuals with previous head trauma also had less taste pores per papillae this was not significant, possibly due to small sample size in the anatomical experiment (N = 19). Bartoshuk et al. pointed out that although participants with a history of otitis media had elevated taste responses, it cannot be assumed that there is a direct causal association since otitis media varies with age, sex, and socio-economic status, and PROP taster status varies with age, sex, and race.

2.8.5 Race

The proportion of PROP non-tasters in the population varies throughout the world, ranging from approximately three percent in western Africa to forty percent in India. In America, approximately thirty percent of the adult Caucasian population are non-tasters (Tepper, 1998; Morton et al., 1981). European populations generally have the highest rates of non-tasters, with the exception of the Basques (in San Sebástian) thought to descend from an older race (Whissell-Buechy, 1990; Boyd and Boyd, 1937-38). Eastern countries generally have the lowest percentage of non-tasters, with the Chinese and Japanese showing especially low rates (Parr, 1934; Sato et al., 1997).

Cultural variation could be due to differing diets in urban and less developed societies. As previously mentioned when discussing evolutionary advantages of inheritance of tasting ability (Section 2.2), heightened taste acuity is advantageous to avoid bitter tasting poisonous wild plants. The disappearance of such plant foods from the diet of urbanised populations in Europe may have relaxed the selection against the recessive t allele.

Most studies looked solely at their own population rather than conducting cross cultural studies. Therefore it is unknown how much of the variation is due to methodology and how much represents a genuine cultural difference.

To summarise, PTC/PROP acuity can be affected by head injuries, ear infections, and hormonal fluctuations, as well as age, sex, and race. X-rays of the head and neck (Kalmus and Farnsworth, 1959) and zinc deficiency (Wills, 1998) have also been associated with taste losses. Therefore an individual's tasting ability may be altered and vary over time, and phenotype may not always be an indicator of genotype. These factors that influence classification of taster groups could potentially affect the outcomes of PROP studies.

2.9 Factors Other Than Taster Status That May Affect Food Choice

Food likes/consumption may be influenced by factors other than taste and PROP taster status, confounding the relationship between taste perception and food likes/dislikes and dietary intake.

Various schemes have been forwarded to account for all of the factors that influence food selection. Shepherd (1990) offered one such scheme. Factors thought to affect food choice were put into three categories: those related to the food, the person, and the economic and social environment. Food related factors included the appearance, taste, odour, and texture of the food, its nutritive value, and the physiological effects following ingestion. Factors related to the person which may influence food selection include hormone levels, illness, intolerance, lifestyle, education, knowledge about nutrition and food preparation, beliefs and values. Environmental factors proposed by Shepherd were the social and cultural environment, religion, availability, convenience of purchase, price, packaging, advertising, marketing, age, sex, social class, region of residence, and degree of urbanisation. These three categories were thought to be interrelated. For example, the sensory properties of foods do not lead to food acceptance or rejection in themselves, it will be the individual's liking for the level of the attribute in a particular food which will influencechoice.

Krondl and Lau (1982) studied the relative importance of different variables influencing food choice. They examined perception of the price, convenience, prestige, health beliefs and taste of the foods and how these related to food consumption. They found that the flavour of the food was the main determinant of food choice. Health beliefs were reported to be less important than tolerance and satiety, and price and convenience were rated as unimportant. However, according to Shepherd, people are not always aware of the importance of different influences on their behaviour and he suggested that it would be better to test the relationship between people's responses to particular foods and their consumption of those foods.

It is clear that numerous factors influence food intake. Despite a heavy body of research, there is not a definitive model of food choice, and the exact nature of the relationships between these factors, and which are most influential is still unknown. This thesis aims to assess the importance of the role of taste perception on food likes/dislikes and intake. Liking/dislikingof the taste of a food does not necessarily predict that it will be eaten, with potential mediating roles of the many other aetiological factors involved in food choice.

2.10 The effect of PROP tasting on Food Likes/Dislikes and Food Intake

Since there is some evidence that PROP tasting ability is associated with acuity for various components found in foods, differential perception of foods may lead to differences in food likes/dislikes and what foods are selected to eat. The following two chapters deal with the effect of PROP acuity on food intake and food likes/dislikes respectively. Factors such as smoking habits and body mass index will also be explored and potential extraneous factors taken into account.

Chapter Three

The Effect of Genetically Mediated Taste Acuity for 6-N-Propylthiouracil (PROP) on Food Intake

3.1 Abstract

Taste acuity for 6-n-propylthiouracil (PROP) is genetically determined (Kalmus, 1971). Non-tasters perceive little or no taste from high concentrations, whereas medium tasters and supertasters perceive a moderate or extremely bitter taste respectively (Bartoshuk, 1993). Heightened PROP sensitivity has been reported to be associated with greater acuity for a variety of compounds found in ordinary foods, although no such trend was observed in some studies. The degree to which these tastes are perceived may affect individuals food likes/dislikes and dietary intake. Although the effects of PROP sensitivity on taste acuity and food likes have been widely researched, very little work has been conducted on food intake. The few existing studies measured responses to food frequency questionnaires (FFQs) rather than actual food consumption. The present study examined data from seven-day food diaries from 104 females, and also included a FFQ for comparison. Food types of interest included: cruciferous and non-cruciferous vegetables; citrus and non-citrus fruits; foods high in fat, sugar, or both; dairy products; caffeine drinks; spicy foods; added salt; alcohol. There was no significant relationship between PROP sensitivity and intake of these food groups, or individual foods within them. No relationship was found when a FFQ was used as a measure of food intake.

3.2 Introduction

Taste acuity to the bitter taste of two chemically related compounds, phenylthiocarbamide (PTC) and 6-n-propylthiouracil (PROP), is a heritable trait (Kalmus, 1971). "Tasters" represent a diverse population whose detection thresholds of PROP can vary by several orders of magnitude. Linda Bartoshuk and her colleagues (Bartoshuk et al., 1992) achieved functional separation of the taster group, the most sensitive of which they named "supertasters". Medium tasters perceive a moderately bitter taste whereas supertasters perceive an extremely bitter taste from concentrated PROP solutions. Non-tasters perceive concentrated PTC and PROP to be mildly bitter or barely detectable. Anatomical evidence supports the distinction of non-tasters, medium tasters and supertasters. The density of taste receptors on the anterior tongue correlates significantly with the perceived bitterness of PROP, and supertasters have the most fungiform papillae, the largest number of taste buds and the highest density of taste buds per papilla (Bartoshuk, Duffy and Miller, 1994).

Genetically mediated sensitivity to PTC and PROP has been associated with greater sensitivity for a variety of compounds found in ordinary foods. PROP supertasters have been shown to perceive the greatest bitterness from several bitter compounds including caffeine, quinine and saccharin, the greatest bitterness and oral burn from ethyl alcohol, and the greatest oral burn from capsaicin (see Tepper, 1998 for a review). Sensitivity to PROP has also been linked with the enhanced perception of sweetness (Bartoshuk, 1979; Gent and Bartoshuk, 1983) and superior ability to discriminate between variations in fat content (Duffy et al., 1996 and Tepper and Nurse, 1997a; Tepper and Nurse, 1997b). However some studies have reported no association between PROP taste perception and perception of some of these compounds (Drewnowski, Henderson, and Shore 1997a, 1997b; Drewnowski, Henderson, and Barratt-Fornell, 1998; Leach and Noble, 1986; Mela, 1989; Smagghe and Louis-Sylvestre, 1998). Psychophysical procedural differences may be responsible for some of these conflicting findings (Prutkin et al., 2000).

There has been very little study of the effect of PROP sensitivity on food intake. The few existing studies measured responses to food frequency questionnaires (FFQs) rather than actual food consumption. FFQs attempt to provide merely a subjective estimate of usual intake and tend to measure attitudes to food names rather than actual consumption patterns (Drewnowski and Rock, 1995). There is evidence that, in the case of fat consumption, perceived intake is not associated with measured intake (Mela, 1996).

One of the earliest studies reported that PTC taster status was not associated with frequency of consumption of thirty-one food items in a food frequency questionnaire (Mattes and Labov, 1989). The types of foods listed included vegetables (in both raw and cooked form without any form of seasoning), fruits, diet cola, black coffee, bittersweet chocolate, walnuts, and milk.

Jerzsa-Latta et al. (1990) investigated the role of PROP acuity on the frequency of intake of eleven cruciferous vegetables and two bitter-tasting non-cruciferous vegetables; spinach and endive. With the exception of radishes, included only in raw form, the vegetables were listed as both raw and cooked. PROP effects were found for only two of the twenty-five items in the questionnaire: non-tasters reported consuming significantly more cooked turnip and raw watercress. However these findings are limited by the small sample size (N = 36), and the infrequency of intake of the vegetables which were eaten mainly on a monthly or occasional basis.

Similarly, several other studies did not find a PTC/PROP effect for self-reported frequency of use of all listed raw and cooked cruciferous vegetables (Niewind, Krondl, and Shrott, 1988; Kaminski, Henderson, and Drewnowski, 2000; Drewnowski, Kristal, and Cohen, 2001). The representativeness of Niewind et al.'s (1988) and Kaminski et al.'s (2000) studies, and thus the results and conclusions drawn from them, are also limited by the small number of participants (N = 32 and N = 50 respectively). However Drewnowski, Kristal, and Cohen (2001) used a larger sample of 364 males and 378 females. All three studies also are limited by the psychophysical procedures used to determine PROP taster status. Niewind et al. did not employ a Wetherill and Levitt (1965) modification in determining the PROP threshold (i.e. reduced the stimulus concentration after one correct response instead of two). Kaminski et al. (2000) and Drewnowski Kristal, and Cohen (2001) classified participants into PROP taster groups by rating the intensity of PROP on category scales, regarded as having ceiling effects that can minimise/wipe out PROP effects (Lucchina et al., 1998b). Mattes and Labov's (1989) study also employed a category scale.

One recent study did identify a relationship between PROP tasting and intake of vegetables. Duffy et al. (2001) assessed vegetable intake using five non-consecutive food records and an interviewed food frequency survey. Participants with heightened PROP tasting ability reported a lower intake of vegetables over five days (food records) and less frequent intake of green vegetables over a year (frequency survey).

Yackinous and Guinard (2000) reported that most measures of food intake did not differ among PROP taster groups (description of method of assessing food intake not provided), though female supertasters had lower carbohydrate and fibre intakes.

Using interviewed food frequency questionnaires, PROP perception was positively correlated with intake of high fat dairy products and negatively correlated with intake of "pungent" foods in a group of older adults (aged 65-95). Although these correlations were significant they were quite small (less than 0.3) and PROP sensitivity showed no significant association with intake of twenty other food groups (Lucchina et al. 1995; Lucchina, unpublished doctoral thesis, 1995). Dabrila et al. (1995) also reported a similar significant but small correlation (r = -0.29) between higher PROP intensity ratings and lower intake of fat using a food frequency questionnaire.

Ly and Drewnowski (2001) examined frequency of consumption of three types of chocolate (white, milk, and dark) and types of coffee in FFQs. The participants were also asked what type of coffee they usually drank and if they took milk/cream and/or sweetener. They found no significant differences in the three taster groups reported consumption of chocolate and coffee. However more tasters (77%) reported taking both milk/cream and sweetener in their coffee than non-tasters (44%). Twenty-two percent of non-tasters drank their coffee black compared to 7% of tasters. A PROP effect on coffee intake may not have been found since the addition of milk and sweeteners masks its bitter taste, thus making it more palatable to tasters. However PROP intensity was rated on a 9-point category scale, which could have obscured potential PROP effects. Using the same category sale, Drewnowski, Henderson and Barratt-Fornell (2001) found that PROP tasters drank significantly less coffee than non-tasters per week (4.6 versus 5.4 servings).

The present study aims to examine the effect of genetically mediated taste acuity for PROP on dietary intake, using food diaries as well as a food frequency questionnaire. There maybe a greater likelihood of identifying potential PROP effects using food diaries since they measure actual rather than estimated food intake. The potential mediating effect of dietary restraint on PROP tasting and food intake will also be explored. PROP effects may be more visible among unrestrained eaters than restrained eaters since they are less motivated to consciously attempt to restrict their food intake to control their weight and therefore their food consumption may be affected more by determinants such as taste.

3.3 Method

3.3.1 Participants

The participants were students and staff at Aston University in Birmingham, England. The sample consisted of 104 females (18 - 45 years; mean age: 21.5, SD: 5.3). All women had to be responsible for their own shopping and cooking to be eligible to participate. Thirty-three women were smokers, and seventy-one were non-smokers. Mean body mass index for the sample was 23.0, SD = 3.6 (range = 16 - 42) which falls in the "acceptable" weight range (20 - 25).

All participants were instructed not to eat, drink (water was allowed), smoke, chew gum or brush their teeth for one hour before their appointment.

3.3.2 Materials

3.3.2.1 Stimuli

The stimuli and procedures used to determine PROP taster status were based on those used by Bartoshuk, Duffy and Miller (1994) and Drewnowski, Henderson, and Barratt-Fornell (1998). Taste thresholds were measured using fifteen PROP (Pfaltz and Bauer, Waterbury, CT) solutions incremented in quarter logarithmic steps, ranging in concentration from 1.0×10^{-6} mol/L (solution 1) to 3.2×10^{-3} mol/L (solution 15). The four most concentrated solutions were prepared using 0.544g/L (solution 15), 0.3064g/L (14), 0.1702g/L (13), and 0.0953g/L (12). The other eleven solutions were made by diluting these four stock solutions.

Filtered tap water was used as a solvent, as a standard, and for water rinses between samples. The solutions were prepared at least 24 hours in advance of testing, and stored in glass bottles, along with the filtered water, at 5°C and presented at room temperature.

Suprathreshold responses were determined using suprathreshold concentrations of PROP and reagent grade sodium chloride (Fisher, Loughborough, UK). The five PROP solutions were solutions 15 (3.2×10^{-3} mol/L), 13 (1.0×10^{-3} mol/L), 11 (3.2×10^{-4} mol/L), 9 (1.0×10^{-4} mol/L), and 7 (3.2×10^{-5} mol/L). The concentrations of NaCl were

1.0, 0.32, 0.10, 0.032, and 0.01 mol/L NaCl (Drewnowski, Henderson, and Barratt-Fornell, 1998). All solutions were presented in 10mL quantities in disposable shot glasses.

3.3.2.2 Food Intake Measures

The participants completed seven-day food diaries (Appendix One) and a food frequency questionnaire (Appendix Two). Number of instances participants reported consuming a particular item was used as units of intake in the food diaries. Boxes were provided for each meal (breakfast, lunch, and dinner) as well as three boxes for snacks between each meal and after dinner. Another box for alcohol consumption was included at the end for each day. There was also a reminder about noting when salt was added to the meal, either to the plate or during cooking.

Participants were asked to indicate on the food frequency questionnaire (FFQ) how often they consumed seventy-four food and drink items during a typical week: never, less than once a week, 1-2 times a week, 3-4 times, 5-6 times, every day, and more than once a day, or not tried. Selection of items were based on those included in a food preference questionnaire (Freeman, unpublished data) in a study of PROP tasting and food likes/dislikes. They comprised foods and drinks that were notably strong tasting and several blander items.

3.3.2.3 Questionnaires

The participants were asked to respond to three questionnaires measuring dietary restraint, salt intake patterns (Appendix Three), and background information (Appendix Four). Stunkard and Messick's (1985) twenty-one item dietary restraint component of three-factor eating questionnaire was administered. Individuals with scores greater than or equal to 10 were assigned as restrained eaters and those with scores less than 10 as unrestrained eaters, the division used by Tepper and Ullrich (1999). Ganley (in a personal correspondence with Stunkard and Messick in 1982) reported high test-retest reliability in a sample of American college students with one month test-retest reliability for the dietary restraint component of 0.93.

The second questionnaire required participants to give details about their salt intake. The following questions were asked: 1. I add salt to my food: a) never, b) occasionally, often. 2. I don't add salt to my food because: a) I don't like the taste, b) health reasons, c) habit. 3. I add salt to: a) just one particular food, b) two to three different foods, c) more than three foods. 4. I: a) taste my meal and then add salt, b) add salt without tasting the food first. 5. Do you add salt when cooking? a) yes, b) no. 6. I add salt when cooking to: a) improve the cooking method, b) improve the taste of the food, c) both improve the cooking method and to improve the taste of the food.

In the background information questionnaire, participants were asked to state their age, smoker status and number of cigarettes smoked (if applicable), as well as respond to questions focused on extraneous factors that could influence PROP tasting ability. These factors included: previous history of head injury (defined as needing hospital treatment); previous or present ear infection; presence or absence of a cold, if they had had an x-ray in the last two weeks; if they wore a dental plate.

3.3.3 Procedure

Participants read and signed an informed consent form and had their height and weight measured before completing the taste tests. They then completed the questionnaires (including the FFQ) and were instructed on how to fill out a food diary in sufficient detail.

3.3.3.1 Determination of PROP thresholds

The determination of PROP thresholds proceeded in two stages: the determination of an approximate threshold which and the determination of a final threshold. Each of these two stages began by allowing the participant to taste the filtered water. This familiarised the respondent with the standard. The water was expectorated in keeping with the sip-and-spit procedure that was followed for tasting of all items. The approximate threshold was the first solution perceived to have a taste from an ascending concentration series, beginning with solution one. To determine the final threshold value the up-down transformed response (UDTR) method (Wetherill and Levitt, 1965) was employed. Participants were presented with pairs of cups, one containing water and the other a PROP solution, and asked to decide which one had the taste. The solution taken as the approximate threshold was presented in the first pair. The stimulus intensity was increased after an incorrect response, and decreased after two consecutive correct responses. This procedure was continued through six reversals (a reversal point being the concentration at which an incorrect choice follows a correct choice or the point at which a correct choice follows an incorrect choice). The first reversal was discarded, and the remaining five averaged to arrive at the final threshold solution.

3.3.3.2 Measurement of suprathreshold responses

The ten suprathreshold solutions of sodium chloride and PROP were presented to the participant in random order, with the NaCl solutions presented first. The samples were tasted using the sip-and-spit procedure with a water rinse between each one (including before the first sample). The participants were asked to assign any number that seemed appropriate to the intensity of the taste of the first solution, with zero indicating no taste at all. They were asked to rate the intensity of the next sample in relation to the first. For example, if the first solution was assigned the number ten, and the second was thought to taste twice as strong, it was given the number twenty. The other samples were rated compared to the one before. The participants were also asked to rate how much they liked each item on a nine-point hedonic preference scale (Peryam and Pilgrim, 1957).

The formula below was calculated in order to separate the tasters into medium tasters and supertasters:

$$\frac{\frac{p_1}{n_1}+\frac{p_2}{n_2}+\frac{p_3}{n_3}+\frac{p_4}{p_5}+\frac{p_5}{n_5}}{5}$$

$P_{1\text{-}5}$ are the bitterness intensity ratings of PROP solutions 7, 9, 11, 13, and 15 respectively, and $n_{1\text{-}5}$ are the saltiness intensity ratings for the five NaCl solutions (1 = weakest NaCl solution, 5 = strongest NaCl solution; Drewnowski et al., 1998). This yielded a mean ratio of the intensity of the five suprathreshold PROP solutions relative to the five NaCl solutions.

Individuals were classified as: 1) non-tasters if their PROP threshold was 10 or above; 2) medium tasters if their PROP threshold was less than 9, and their PROP/NaCl ratio was *less than* 1.2; 3) supertasters if their PROP threshold was less than 9 and their PROP/NaCl ratio was *greater than* 1.2 (Bartoshuk, 1993).

3.3.4 Statistics

3.3.4.1 PROP Taster Status and Intake of Foods (Food Diaries)

One-way MANOVA analyses were used to examine the effect of PROP taster status (non-tasters, medium tasters, and supertasters) on food intake when intake of foods were correlated. Pillai's criterion was used since there were unequal numbers of non-tasters, medium tasters, and supertasters. For clarity, unless otherwise stated all univariate and stepdown F values were not significant and are not reported. Separate ANOVA analyses were used when intake of the foods were not correlated (or when there was only one food item). When the assumptions of ANOVA were not met Kruskal-Wallis analyses were performed. Chi-square tests were carried out when foods were rarely eaten (e.g. cruciferous vegetables) and to examine responses to the salt questionnaire.

3.3.4.2 Food Frequency Questionnaires

Spearman's rank correlation coefficients were used to measure associations between PROP acuity and reported frequency of intake in FFQs and to examine the relationship between dietary restraint and food consumption for both food diaries and FFQs. Pearson's correlations were similarly used to measure associations between PROP acuity and number of instances of intake in food diaries.

3.3.4.3 BMI/Smoking/Extraneous Factors

The effect of PROP taster status on body mass index (BMI) was examined using ANOVA. A Chi-square test was used to investigate differences in smoker status between non-tasters, medium tasters, and supertasters. Differences in the number of cigarettes smoked by the three taster groups were analysed using a Kruskal-Wallis test. The Mann-Whitney test was employed to determine whether smokers and non-smokers differed in their PROP tasting ability. Independent t-tests were used to compare PROP acuity in individuals with and without various pathologies (e.g. colds, ear infections, head injuries).

3.4 Results

3.4.1 Frequencies of Non-tasters, Medium Tasters, and Supertasters

There were 16 non-tasters, 61 medium tasters, and 27 supertasters (NTs = 15.4%; MTs = 58.7%, STs = 26.0%). The three taster groups did not significantly differ in age: $H = 3.88$; $df = 2$; $p > 0.05$. PROP thresholds were bimodally distributed (Figure 3.1).

3.4.2 PROP/NaCl Liking

Liking of PROP and NaCl solutions (1 = like extremely, 9 = dislike extremely) decreased with increasing concentration for all three tasters groups (Figures 3.2 and 3.3). Supertasters disliked the suprathreshold PROP solutions more than non-tasters and medium tasters. This difference was significant for the four strongest solutions (all Hs > 17.13; all ps < 0.01) but not the lowest concentration ($H = 1.831$, $df = 2$, $p > 0.05$).

In contrast to the hedonic ratings of the PROP solutions, PROP taster status had no significant effect on liking of all five NaCl solutions (Figure 3; all Hs < 2.37; all ps > 0.05).

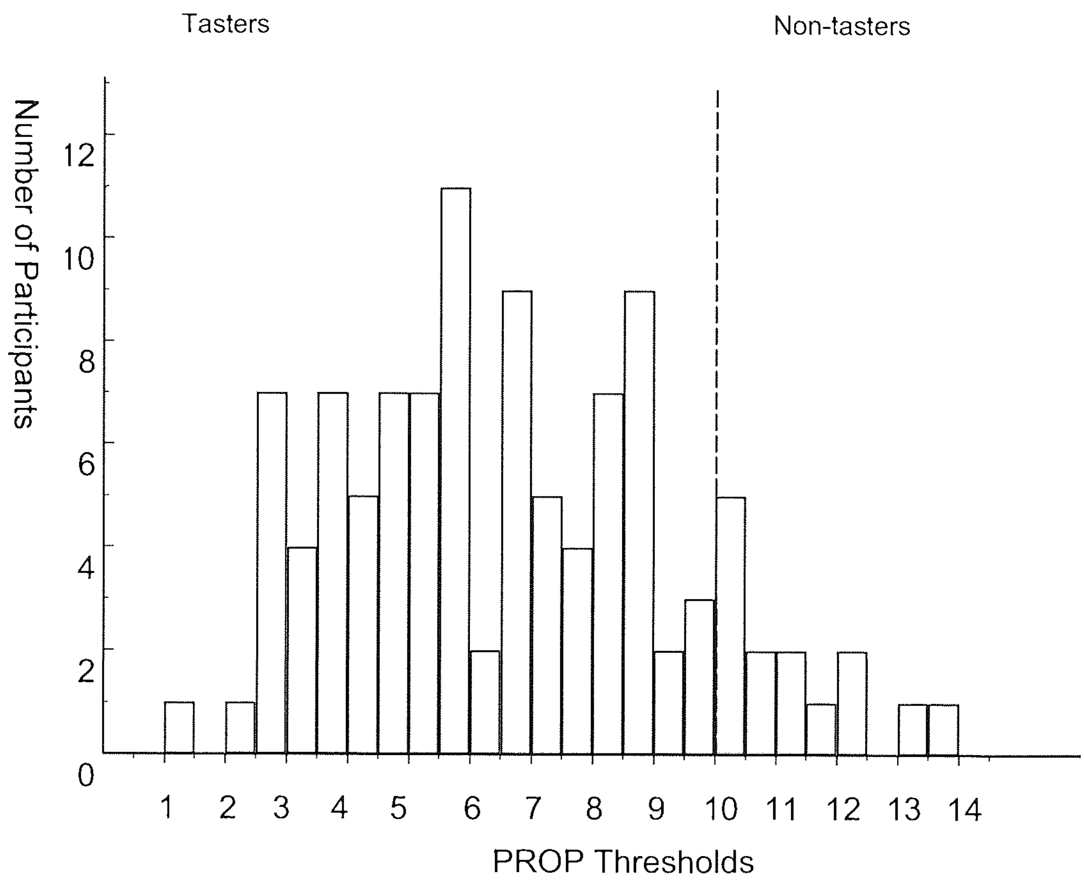

FIGURE 3.1
DISTRIBUTION OF PROP THRESHOLDS

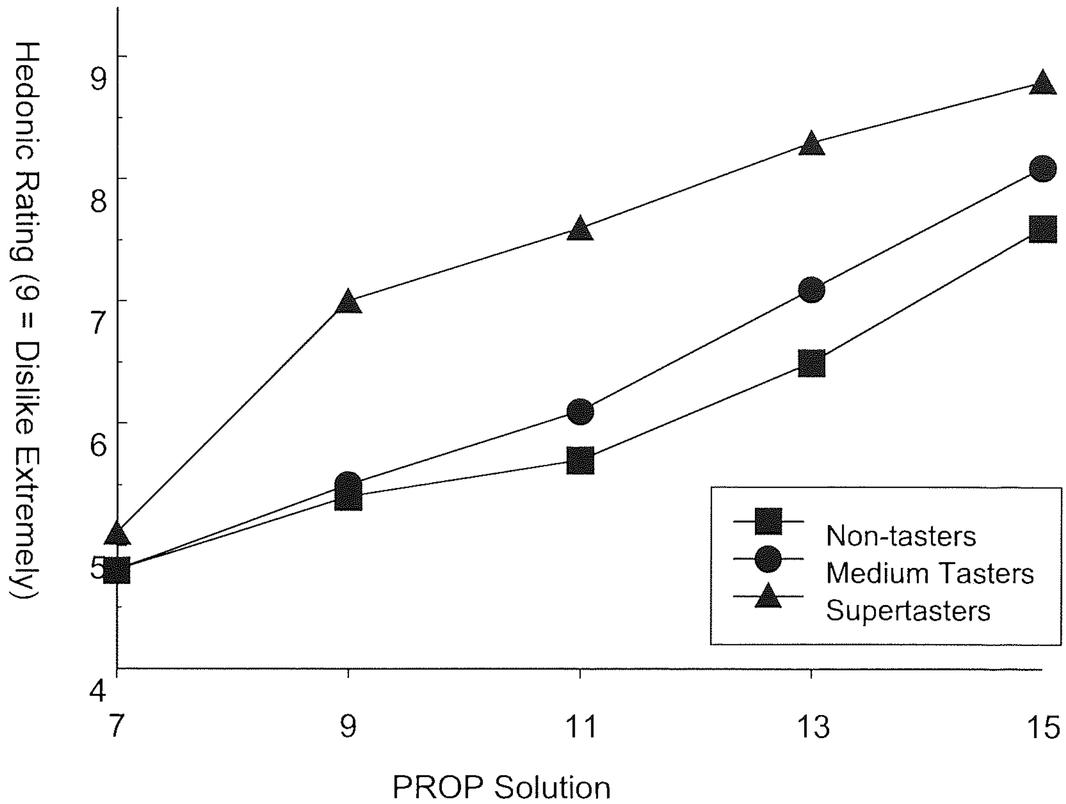

FIGURE 3.2
HEDONIC RATINGS FOR PROP SOLUTIONS AS A FUNCTION OF PROP CONCENTRATION

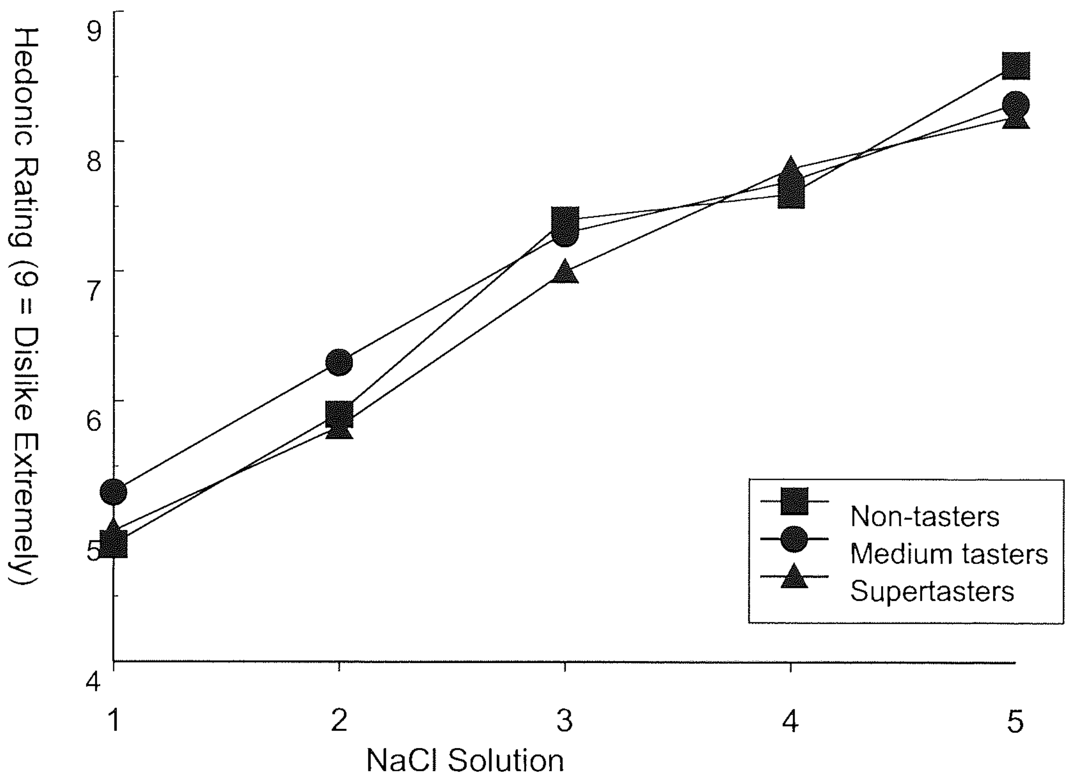

FIGURE 3.3
HEDONIC RATINGS FOR NACL SOLUTIONS AS A FUNCTION OF NACL CONCENTRATION

3.4.3 The Effect of PROP Taster Status on Food Consumption (Food Diaries)

3.4.3.1 Food groups

A one-way between subjects MANOVA was employed to examine the effect of PROP taster status (non-tasters, medium tasters, and supertasters) on consumption of twelve types of foods. The types of foods of interest were: cruciferous vegetables (broccoli, cauliflower, cabbage, kale, turnips, watercress, Brussels sprouts, collard, kohlrabi, radishes) non-cruciferous vegetables (all other vegetables excluding cruciferous vegetables); citrus fruit (lemons, limes, oranges, pineapple); non-citrus fruit (all other fruit apart from citrus fruit); high fat foods (e.g. crisps); sweet foods (e.g. cola); foods high in both fat and sweet ("Fat & Sweet"; e.g. chocolate, cake); tea and coffee ("Caffeine"); alcohol (all alcoholic drinks); dairy products (margarine, butter, yoghurt, milk, eggs, cheese); hot/spicy foods (e.g. curry, chilli); salt added to the plate and during cooking. Dairy products were considered separately from the "high fat foods" group. These groups were derived by common sense classification, and were selected because they were strong tasting. Intake was specified as the number of instances participants reported intake of a particular item, except in the case of alcohol where alcohol units were used (1 unit = half pint/single spirit measure/small glass of wine).

TABLE 3.1
PROP TASTER STATUS AND MEAN WEEKLY INTAKE (NUMBER OF INSTANCES) OF FOOD TYPES

Type of Food	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Cruciferous Vegetables	1 (1.9)	2 (1.8)	2 (1.6)
Non-cruciferous vegetables	13 (7.7)	18 (10.3)	18 (10.2)
High Fat Foods	21 (10.2)	16 (8.3)	21 (8.6)
Sweet Foods	34 (19.6)	27 (16.4)	33 (14.9)
Fat & Sweet	11 (7.3)	9 (7.3)	11 (6.7)
Citrus Fruit	2 (2.0)	4 (4.4)	3 (3.2)
Other Fruit	3 (4.6)	4 (4.0)	3 (3.2)
Dairy Products	21 (14.0)	20 (10.9)	17 (8.2)
Caffeine	7 (9.8)	11 (9.5)	9 (6.7)
Spicy Foods	2 (2.4)	2 (2.6)	2 (2.3)
Added Salt	5 (4.9)	4 (3.2)	3 (3.4)
Alcohol (units)	19 (19.1)	16 (16.0)	15 (15.7)

There was a tendency for non-tasters to consume slightly more alcohol and dairy products, and less non-cruciferous vegetables than supertasters (Table 3.1). Based on Pillai's criterion, taster status did not have a significant multivariate effect on intake of the 12 food groups: $F(24, 182) = 1.281$; $p > 0.05$. The Stepdown F value for fat was significant ($F[2, 95] = 4.423$, $p < 0.05$), but there was no PROP effect on fat consumption since the univariate F statistic was not significant at an alpha level of 0.004, the level employed to reduce the probability of a type one error ($F[2, 101] = 3.529$, $p > 0.004$).

3.4.3.2 Individual Cruciferous Vegetables

TABLE 3.2
PROP TASTER STATUS AND MEAN WEEKLY INTAKE (NUMBER OF INSTANCES) OF INDIVIDUAL CRUCIFEROUS VEGETABLES

Cruciferous Vegetables	Mean (SD)		
	Non-tasters	Medium Tasters	Super-tasters
Broccoli	0.4 (0.6)	0.7 (1.0)	0.6 (0.7)
Brussels sprouts	0.1 (0.3)	0.1 (0.3)	0.0 (0.2)
Cabbage	0.4 (1.0)	0.7 (1.3)	0.8 (1.3)
Cauliflower	0.2 (0.5)	0.3 (0.8)	0.3 (0.7)
Turnips	0.0 (0.0)	0.0 (0.3)	0.0 (0.0)
Watercress	0.1 (0.3)	0.0 (0.1)	0.0 (0.0)

Collard, kale, kohlrabi, and radishes were not eaten at all by anyone in the sample, and only two people ate turnips and watercress. The remaining cruciferous vegetables (broccoli, cauliflower, cabbage, Brussels sprouts) were rarely eaten. Chi-square tests showed no associations between PROP taster status and intake of: broccoli ($\chi^2 = 0.733$, $df = 2$, $p > 0.05$); cabbage ($\chi^2 = 2.215$, $df = 2$, $p > 0.05$); cauliflower ($\chi^2 = 0.750$, $df = 2$, $p > 0.05$); Brussels sprouts ($\chi^2 = 1.245$, $df = 2$, $p > 0.05$). No associations were found when the non-taster and medium taster groups were combined in the chi-square analysis (broccoli: $\chi^2 = 0.385$, $df = 1$, $p > 0.05$; cabbage: $\chi^2 = 0.820$, $df = 1$, $p > 0.05$); cauliflower ($\chi^2 = 0.615$, $df = 1$, $p > 0.05$); Brussels sprouts ($\chi^2 = 0.532$, $df = 1$, $p > 0.05$).

3.4.3.3 Dairy Products

TABLE 3.3
PROP TASTER STATUS AND MEAN WEEKLY INTAKE (NUMBER OF INSTANCES) OF INDIVIDUAL DAIRY PRODUCTS

Dairy Products		Mean (SD)		
		Non-tasters	Medium Tasters	Supertasters
Milk	N = 104	14 (11.7)	13 (9.9)	10 (7.9)
Eggs	N = 104	0 (0.4)	2 (1.8)	1 (2.1)
Cheese	N = 104	5 (4.2)	5 (3.2)	5 (2.5)
Butter	N = 75	2 (3.4)	1 (1.4)	1 (2.4)
Margarine	N = 75	5 (5.8)	6 (4.9)	6 (4.3)
Yoghurt	N = 104	1 (2.8)	1 (1.5)	0 (0.9)

There were 29 missing cases for margarine and butter since initial participants did not remember to note this, and subsequent participants were reminded. All three taster groups had similar mean intakes of all the dairy products, although intake of milk was slightly higher for non-tasters than for supertasters (Table 3.3).

Two one-way between subjects MANOVAs were carried out. One examined the effect of PROP taster status (non-tasters, medium tasters, and supertasters) on consumption of margarine and butter, and the other the effect on the intake of eggs, milk cheese and yoghurt.

Taster status did not have a significant multivariate effect: on intake of margarine and butter ($F(4, 144) = 0.058$; $p > 0.05$) or yoghurt, milk, eggs, and cheese: $F(8, 198) = 1.739$; $p > 0.05$. Although the stepdown value was significant at the 0.05 level for eggs ($F[2, 99] = 4.35$, $p<0.05$), we cannot conclude that PROP sensitivity influences egg intake since the univariate value was not significant ($F[2, 101] = 4.32$, $p > 0.0125$). The descriptive statistics showed that medium tasters consumed the most eggs out of the three taster groups, and non-tasters the least, although these differences were very small (Table 3.3).

3.4.3.4 Tea and Coffee

TABLE 3.4
MEDIAN WEEKLY INTAKE OF TEA AND COFFEE

	Median (Interquartile Range)		
	Non-tasters	Medium Tasters	Supertasters
Tea	2 (10.3)	6 (15.0)	5 (11.0)
Coffee	0 (11.3)	1 (4.0)	0 (3.0)

The three taster groups had higher median intakes of tea than coffee. Medium tasters' and supertasters' median intake of tea was higher than that of non-tasters (Table 3.4). Kruskal-Wallis tests showed that the three taster groups' intake of both tea ($H = 2.31$; $df = 2$ $p > 0.05$) and coffee ($H = 0.31$; $df=2$; $p > 0.05$) were not significantly different.

3.4.3.5 White and Wholemeal Bread

Two participants did not indicate which type of bread they ate (one non-taster, one medium taster). The sample in general consumed more white bread than wholemeal bread (Table 3.5). All three taster groups consumed similar amounts of white and brown bread ($F[4, 198] = 0.900$; $p > 0.05$).

TABLE 3.5
MEAN WEEKLY INTAKE OF BROWN AND WHITE BREAD

Type of Bread	Mean (SD)		
	Non-tasters	Medium Tasters	Super-tasters
White Bread	15 (10.0)	13 (8.3)	16 (7.6)
Brown Bread	3 (6.8)	4 (5.5)	3 (6.1)

* 1 unit = 1 slice of bread, 1 roll, small baguette

** Brown bread = brown, wholemeal and granary breads

3.4.3.6 Milk and Sugar in Tea/Coffee

Nineteen participants did not drink tea or coffee. One person took milk in their tea/coffee only occasionally, and three people varied in how much sugar they took, so were dropped from the analysis. Therefore 84 participants contributed to the analysis that looked at the effect of PROP taster status on whether people take milk in their tea/coffee. Eighty-two participants contributed data to the analysis of the effect of PROP taster status on how much sugar is taken in tea/coffee.

TABLE 3.6
FREQUENCY OF NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS WHO TAKE MILK IN TEA/COFFEE

	Take milk in tea	
	Yes	No
Non-tasters	10 (83%)	2 (17%)
Medium Tasters	44 (90%)	5 (10%)
Supertasters	19 (83%)	4 (17%)
Total	73 (87%)	11 (13%)

Seventy-three of the 84 participants in the analysis took milk in their tea or coffee (Table 3.6). A chi-square test showed that there was no association between PROP taster status and whether milk was taken in tea and coffee ($\chi^2 = 0.867$, $df = 2$, $p > 0.05$).

There was little difference between the three taster groups' median number of teaspoons of sugar taken in tea and coffee (Table 3.7). A Kruskal-Wallis test confirmed this ($H = 5.18$; $df = 2$; $p > 0.05$).

TABLE 3.7
PROP TASTER STATUS AND MEDIAN NUMBER OF TEASPOONS OF SUGAR IN TEA/COFFEE

	Median (Interquartile Range)	Total
Non-tasters	1 (2.0)	12
Medium Tasters	0 (1.0)	47
Supertasters	1 (1.5)	23

3.4.3.7 Miscellaneous Eating Behaviours

PROP taster status had no significant effect on: 1) the number of different foods eaten in one week: $H = 1.27$; $df = 2$; $p > 0.05$; 2) number of times a snack (defined as food/drinks consumed between meals) was eaten in one week: $H = 0.16$, $df = 2$; $p >$

0.05; 3) number of times breakfast was eaten in one week: $H = 1.68$; $df = 2$; $p > 0.05$ (Table 3.8).

TABLE 3.8
MEDIAN NUMBER OF EATING BEHAVIOURS

Eating Behaviour	Median (Interquartile Range)		
	Non-tasters	Medium Tasters	Supertasters
Number of foods items	46 (18.8)	51 (9.0)	48 (14.0)
Choosing a snack (max 21)	14 (4.8)	13 (5.0)	13 (4.0)
Taking breakfast	6 (2.0)	5 (3.0)	5 (3.0)

PROP sensitivity also had no effect on type of cuisine eaten as an evening meal. Few participants ate Mexican (N = 11) or Turkish/Greek (N = 2) food for dinner so these types of cuisine were not included in the MANOVA analysis. The other types of meal eaten were Italian, Chinese, Indian, and British/Western (Table 3.9). PROP taster status did not have a significant multivariate effect on type of cuisine eaten as an evening meal: $F(8, 198) = .574$; $p > 0.05$.

TABLE 3.9
MEAN FREQUENCY OF TYPE OF CUISINE EATEN FOR DINNER

Cuisine	Mean (SD)		
	Non-tasters	Medium Tasters	Super-tasters
Italian	1.7 (1.5)	2.0 (1.2)	1.8 (1.5)
Chinese	0.3 (0.8)	0.4 (0.7)	0.5 (0.6)
Indian	0.8 (1.2)	0.7 (1.2)	0.7 (1.3)
British	3.8 (1.6)	3.5 (1.7)	3.4 (1.6)

3.4.3.8 Type and Variety of Alcoholic Drinks

It was previously reported (Table 3.1) that non-tasters tended to consume slightly, but not significantly, more alcohol units per week than supertasters (NTs = 19.4, MTs = 16.5, STs = 15.3). Non-tasters, medium tasters, and supertasters drank a similar number of units of several different types of alcoholic drinks (Table 3.10). There was a trend for consumption of lager, with non-tasters and medium tasters drinking more than supertasters. PROP tasting ability did not have a significant multivariate effect on frequency of consumption of all of these types of alcoholic drinks: $F(22, 184) = 0.688$;

$p > 0.05$. PROP taster status also had no significant effect on the variety (number of different types) of alcoholic drinks consumed in one week: $F(2, 101) = 0.94$; $df = 2$; $p > 0.05$.

TABLE 3.10
NON-TASTERS', MEDIUM TASTERS' AND SUPERTASTERS' MEAN WEEKLY INTAKE OF A NUMBER OF ALCOHOLIC DRINKS (ALCOHOL UNITS)

	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Lager	5.2 (7.3)	4.4 (7.1)	1.8 (4.2)
Lager and fruit	0.4 (1.5)	0.4 (1.9)	0.9 (2.8)
Bitter	0.0 (0.0)	0.5 (2.6)	1.8 (7.0)
Cider	0.9 (2.6)	1.5 (4.8)	1.1 (2.5)
Cider and fruit	0.1 (0.5)	0.7 (3.4)	0.5 (2.5)
Spirit	0.6 (1.1)	0.8 (2.1)	1.0 (2.3)
Spirit and mixer	5.8 (10.1)	2.9 (4.7)	4.2 (10.3)
Gin/Vodka tonic	0.0 (0.0)	0.3 (1.6)	0.1 (0.4)
Red wine	1.7 (4.2)	1.4 (3.8)	0.3 (0.7)
White wine	1.0 (2.2)	2.7 (6.1)	2.1 (3.9)
Alcopops	2.7 (4.0)	1.5 (3.4)	1.5 (3.1)
Total	19.4 (19.1)	16.5 (16.0)	15.3 (15.7)

3.4.4 Salt Questionnaire

There was no association between PROP taster status and: 1) self-reported frequency of adding salt to food ($\chi^2 = 3.424$, $df = 4$, $p > 0.05$); 2) reasons why salt is not added to food ($\chi^2 = 4.435$, $df = 4$, $p > 0.05$); 3) self-reported number of foods salt is added to ($\chi^2 = 8.228$, $df = 4$, $p > 0.05$); 4) whether people add salt before or after tasting their meal ($\chi^2 = 1.360$, $df = 2$, $p > 0.05$); 5) whether salt is added during cooking ($\chi^2 = 0.706$, $df = 2$, $p > 0.05$); 6) reasons why salt is added during cooking ($\chi^2 = 0.620$, $df = 4$, $p > 0.05$). There were no PROP effects when the non-tasters and medium tasters were combined into one group and compared with the supertasters (Question 1: $\chi^2 = 2.096$, $df = 2$, $p > 0.05$; Q2: $\chi^2 = 0.754$, $df = 2$, $p > 0.05$; Q3: $\chi^2 = 0.597$, $df = 2$, $p > 0.05$; Q4: $\chi^2 = 1.116$, $df = 1$, $p > 0.05$; Q5: $\chi^2 = 0.191$, $df = 1$, $p > 0.05$; Q6: $\chi^2 = 0.255$, $df = 2$, $p > 0.05$).

3.4.5 The Effect of PROP Acuity on Food Frequency Questionnaire Responses

3.4.5.1 Food Groups

Foods in the food frequency questionnaire were put into food categories, as carried out with the food diary data, to enable comparison of how the two measures of intake relate to PROP acuity. There were no non-citrus fruits in the FFQ, and the category of "salt added to food" (on plate or when cooking) was also not included in this measure. The mean scores in table 3.11 represent categories in the food frequency questionnaire (1 = never eat this food; 2 = less than once a week; 3 = 1-2 times a week; 4 = 3-4 times; 5 = 5-6 times; 6 = every day; 7 = more than once a day). The participants reported eating most food types infrequently, and the means show little differences between the three taster groups self-reported estimates of their frequency of consumption.

TABLE 3.11
PROP TASTER STATUS AND MEAN WEEKLY INTAKE OF FOOD TYPES MEASURED USING A FOOD FREQUENCY QUESTIONNAIRE

Type of Food	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Cruciferous Vegetables	1.2 (0.3)	1.3 (0.4)	1.3 (0.3)
Non-cruciferous vegetables	2.0 (0.5)	2.1 (0.5)	2.2 (0.5)
High Fat Foods	2.3 (0.4)	2.0 (0.4)	2.2 (0.4)
Sweet Foods	2.1 (0.3)	2.0 (0.5)	2.2 (0.4)
Fat & Sweet	2.2 (0.5)	2.0 (0.5)	2.3 (0.6)
Citrus Fruit	1.5 (0.5)	1.7 (0.8)	1.4 (0.4)
Dairy Products	2.9 (0.6)	2.7 (0.6)	2.9 (0.7)
Caffeine	2.1 (1.3)	2.3 (1.1)	1.8 (1.1)
Spicy Foods	1.9 (1.0)	2.0 (0.9)	2.3 (1.3)
Alcohol (units)	1.8 (0.8)	2.0 (0.6)	1.7 (0.8)

There was no multivariate effect of PROP taster status on frequency of intake ($F[20, 186] = 1.560$; $p > 0.05$) although Pillai's trace did approach significance ($p = 0.67$). Only the univariate test for high fat foods was significant at an alpha level of 0.005 ($F[2, 101] = 5.485$; $p < 0.005$), although the corresponding stepdown value was not ($F[2, 93] = 1.948$; $p > 0.05$), indicating no PROP effect. Conversely the stepdown tests for fat & sweet foods ($F[2, 96] = 4.810$; $p < 0.05$), and citrus fruits ($F[2, 95] = 3.416$; $p < 0.05$), were significant but there were no univariate effects (fat x sweet: $F[2, 101] = 4.477$; $p < 0.005$; citrus: $F[2, 101] = 1.986$; $p < 0.005$), also indicating no PROP effects.

High fat foods (*rho* = 0.33; $p < 0.001$) and those high in fat and sweet (*rho* = 0.20; $p < 0.05$) had small but significant correlations with PROP thresholds. Women with higher thresholds (lower sensitivity to the taste of PROP) ate more high fat and sweet/fatty foods than women with lower thresholds (higher sensitivity to PROP). When groups of foods in the FFQ were correlated with PROP/NaCl ratios, only caffeine had a significant association (*rho* = -0.23; $p < 0.05$), with intake of tea and coffee decreasing with increased PROP tasting ability.

There were no significant correlations between thresholds and any of the food categories when actual food intake was measured using food diaries (using Pearson's R). However, looking at PROP/NaCl ratios, intake of high fat foods ($r = 0.20$; $p < 0.05$) and vegetables (cruciferous and non-cruciferous combined: $r = 0.21$; $p < 0.05$) increased with increasing suprathreshold PROP responses.

3.4.5.2 Individual Foods

PROP thresholds were significantly correlated with reported consumption of: bacon, biscuits, chips, fish and chips, and Sunday roast, and approached significance for crisps and dark chocolate (Table 3.12). Individuals with higher thresholds (low PROP sensitivity) reported eating these high fat foods more often than participants with lower thresholds (higher PROP sensitivity). When the food items in the FFQ were correlated with PROP/NaCl ratios rather than PROP thresholds, different foods had significant associations. Heightened PROP acuity was associated with decreased frequency of consumption of coffee without sugar and horseradish, and increased consumption of white bread (Table 3.13). Although the correlations were significant, they were very small indicating only a very weak relationship between PROP perception and reported consumption of these foods in the 74-item FFQ. The correlations between PROP/NaCl ratios and reported frequency of consumption of parsnip and endive approached significance. Intake of parsnip decreased with increasing PROP tasting ability, and intake of endive increased.

TABLE 3.12
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP THRESHOLDS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES

Thresholds	Rho
Bacon	0.26**
Biscuits	0.20*
Chips	0.36***
Fish and chips	0.23*
Sunday roast	0.20*
Crisps	0.19, p = 0.056
Dark chocolate	0.19, p = 0.051

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed
*** $p < 0.001$, two-tailed

TABLE 3.13
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP/NACL RATIOS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES

PROP/NaCl Ratio	Rho
Coffee- no sugar	-0.22*
Horseradish	-0.21*
White bread	0.25*
Parsnip	-0.19, p = 0.053
Endive	0.18, p = 0.062

* $p < 0.05$, two tailed

3.4.5.3 Separating the Three Taster Groups

Non-tasters with the highest PROP thresholds (i.e. the least PROP sensitive of the non-taster group) reported eating several bitter and sweet tasting foods more often than non-tasters with the lowest PROP thresholds (Table 3.14). The least sensitive non-tasters also ate less boiled potatoes, a bland food. Correlations for medium tasters were somewhat smaller. The least PROP sensitive of the medium taster group reported eating chips and several vegetables (turnip, watercress, and swede) more frequently than the most PROP sensitive medium tasters.

There were significant negative correlations between PROP thresholds and supertasters' intake of individual cruciferous and non-cruciferous vegetables, as well as the group of non-cruciferous vegetables as a whole, i.e. the most sensitive supertasters (and most sensitive of the whole sample) tended to eat less of these vegetables than the less sensitive supertasters. The most sensitive supertasters also reported a higher frequency of consumption of mayonnaise, crisps, and high fat foods in general.

TABLE 3.14
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP THRESHOLDS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Non-tasters (N = 16)		Medium Tasters (N = 61)		Supertasters (N = 27)	
Blue cheese	0.63**	Chips	0.29*	Crisps	0.41*
Boiled potatoes	-0.58*	Swede	0.30*	Endive	-0.43*
Diet Cola	0.52*	Turnip	0.32*	Honey	-0.51**
Grapefruit/juice	0.51*	Watercress	0.28*	Horseradish	-0.42*
Honey	0.59*			Kale	-0.42*
				Mayonnaise	0.44*
				Runner beans	-0.46*
				Spinach	-0.41*
				Watercress	-0.40*
				FAT	0.46*
				NONCRUC	-0.49**

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

There were little or no significant correlations between frequency of intake of items in the FFQ and PROP/NaCl ratios for non-tasters and supertasters (Table 3.15). Among non-tasters, higher PROP/NaCl ratios (i.e. greater PROP acuity) were associated with decreased intake of coffee with sugar. Medium tasters with the highest PROP/NaCl ratios ate less chilli peppers, onions, parsnips, turnips, and the group of non-cruciferous vegetables as a whole than those with lower PROP/NaCl ratios.

TABLE 3.15
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP/NACL RATIOS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Non-tasters (N = 16)		Medium Tasters (N = 61)		Supertasters (N = 27)
Coffee with sugar	0.52*	Chilli pepper	-0.26*	
		Onions	-0.26*	
		Parsnips	-0.33**	
		Turnip	-0.29*	
		NON-CRUC VEG	-0.26*	

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

Using number of instances of consumption in food diaries as a measure of food intake, the only group of foods that had a significant correlation with PROP thresholds was supertasters' intake of caffeine ($r = 0.45$, $p < 0.05$). This seems to be attributable to supertasters intake of tea ($r = 0.42$, $p < 0.05$) rather than bitter tasting coffee ($r = 0.05$, $p > 0.05$). The most PROP sensitive supertasters (with the lowest PROP thresholds) ate more brown bread than the less sensitive supertasters ($r = -0.41$, $p < 0.05$). The least sensitive non-tasters consumed more margarine than most sensitive non-tasters ($r = 0.68$, $p < 0.05$).

Using PROP/NaCl ratios rather than PROP thresholds, non-tasters with highest PROP acuity reported consuming more alcohol (specifically lager and spirits with mixers) and less high fat foods and high fat/sweet foods than non-tasters with lower PROP acuity (Table 3.16). Medium tasters who found PROP to be the most intense consumed less grapefruit than medium tasters who rated PROP as less intense. Among supertasters, those with the highest PROP intensity ratings consumed the most vegetables as a whole, specifically the most cruciferous vegetables including cabbage.

TABLE 3.16
PEARSON'S CORRELATION COEFFICIENTS BETWEEN PROP/NACL RATIOS AND NUMBER OF INSTANCES OF INTAKE IN FOOD DIARIES FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Non-tasters (N = 16)		Medium tasters (N = 61)		Supertasters (N = 27)	
Fat	-0.61*	Grapefruit	-0.27*	Cruciferous veg	0.46*
Fat X sweet	-0.64**			Cabbage	0.59**
Alcohol	0.54*			Vegetables	0.42*
Lager and fruit	0.72**				
Spirit and mixer	0.51*				

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

3.4.6 Effect of Dietary Restraint on Food Consumption

3.4.6.1 Food Diaries

One-way MANOVA analysis showed that dietary restraint had no significant multivariate effect on the consumption of the twelve food categories in the food diaries ($F[12, 91] = 0.921$; $p > 0.05$). There was also no multivariate effect for dietary restraint on: margarine or butter ($F[2, 72] = 2.502$; $p > 0.05$); yoghurt, milk, eggs, or cheese ($F[4, 99] = 0.932$; $p > 0.05$) or any of the ten types of alcoholic drinks ($F[10, 93] = 0.828$; $p > 0.05$) The individual cruciferous vegetables were not eaten often enough to enable inferential analysis but consumption means revealed no effect of dietary restraint on instances of their consumption: broccoli (unrestrained eaters: 0.6; restrained: 0.6); cauliflower (0.3, 0.3); cabbage (0.7, 0.5); brussels sprouts (0.1, 0.1), turnips (0.0, 0.01), watercress (0.0, 0.0). Restrained and unrestrained eaters also drank similar amounts of tea ($U = 879.5$, $p > 0.05$) and coffee ($U = 831.0$, $p > 0.05$), and put similar amounts of sugar in tea/coffee ($U = 552.0$, $p > 0.05$).

Restrained eaters ate significantly more brown bread ($U = 672.5$, $p < 0.05$) and less white bread ($U = 474.5$, $p < 0.05$) than unrestrained eaters. Unrestrained eaters' median intake of brown bread was 0 (interquartile range = 5.0) compared to 3 (interquartile range = 10.5) for restrained eaters. Unrestrained eaters ate more than twice as much white bread as restrained eaters did: unrestrained = 15 (interquartile range = 11.5), restrained = 6.5 (interquartile range = 9.5)

3.4.6.2 Food Frequency Questionnaires

For both food diaries and FFQs, intake of high fat foods, dairy products, and caffeine decreased with increasing levels of dietary restraint. A negative relationship was also found for milk and white bread for both intake measures, and intake of brown bread increased with restraint scores (Table 3.17). Frequency of consumption of several individual high fat and high sugar foods listed in the FFQ also decreased with increasing restraint scores. Several low fat foods including boiled potatoes and cottage cheese increased with high levels of dietary restraint. Although these relationships were significant it must be noted that the size of the correlations were quite small, suggesting that the associations are relatively weak.

TABLE 3.17
SPEARMAN'S CORRELATION COEFFICIENTS BETWEEN DIETARY RESTRAINT SCORES AND CONSUMPTION OF FOODS AS MEASURED BY FOOD DIARIES AND FOOD FREQUENCY QUESTIONNAIRES

Food Diary		Food Frequency Questionnaire	
Milk	-0.21*	Bacon	-0.27**
Yoghurt	0.26**	Biscuits	-0.24*
Tea	-0.27**	Boiled potatoes	0.20*
Coffee	-0.22*	Brown bread	0.33**
Brown bread	0.32**	Cola	-0.22*
White bread	-0.41**	Cottage cheese	0.24*
Non-citrus fruit	0.21*	Crisps	-0.37**
Fat	-0.20*	Diet cola	0.32**
Caffeine	-0.32**	Fish and chips	-0.28**
Dairy	-0.25*	Fried breakfast	-0.27**
		Margarine	-0.26**
		Mayonnaise	-0.26*
		Full fat milk	-0.34**
		Milk chocolate	-0.20*
		Sausages	-0.39**
		Spinach	0.37**
		Sunday roast	-0.35**
		White bread	-0.38**
		Fat	-0.43**
		Dairy	-0.21*
		Caffeine	-0.21*

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

3.4.7 The Effect of Dietary Restraint on the Relationship between PROP Tasting Ability and Food Intake

It is possible that dietary restraint could have negated a potential PROP effect on food consumption, particularly since the sample is female. PROP effects on food intake may be expected to be more evident among the unrestrained eaters as their food choice is less determined by dietary restraint, and therefore could be more influenced by other factors such as taste. To test this hypothesis some of the above analyses were conducted with the unrestrained eaters only (N = 77; 11 NTs, 43 MTs, 23 STs). The restrained group was too small (N = 27; 5 NTs, 18 MTs, 4 STs) to carry out inferential statistics.

3.4.7.1 Food Diaries

When a PROP effect on the 12 main categories of foods was explored, there was still no multivariate effect: F (24, 128) = 1.158, $p > 0.05$. Also as before, although the stepdown F statistic for fat was significant ($F[2, 63] = 3.287$, $p < 0.05$), the univariate value was not significant and therefore there was no PROP effect of fat intake among unrestrained eaters.

There was also no PROP effect among unrestrained eaters for intake of butter and margarine ($F[4, 108] = 2.059$, $p > 0.05$). Although the univariate ($F[2, 54] = 3.867$, $p >$ 0.027) and stepdown F statistics ($F[2, 54] = 3.867$, $p > 0.05$) for butter were not significant, the univariate F value neared significance (p = 0.027, alpha = 0.025). Intake of yoghurt, milk, eggs, and cheese were not correlated, permitting separate ANOVA analyses. Although there was no effect of PROP taster status on intake of yoghurt ($F[2, 74] = 1.374$, $p > 0.05$), milk ($F[2, 74] = 1.530$, $p > 0.05$), and cheese ($F[2, 74] = 0.132$, $p > 0.05$), there was a PROP effect for eggs ($F[2, 74] = 4.222$, $p < 0.05$). Scheffé post-hoc tests revealed that non-tasters intake of eggs was significantly different from that of medium tasters (Table 3.18). Medium tasters (1.7, SD = 1.8) had a higher mean intake of eggs than non-tasters (0.2, SD = 0.4) and supertasters (0.8, SD = 2.0).

TABLE 3.18
SCHEFFÉ POST HOC TESTS FOR EFFECT OF PROP TASTER STATUS ON INTAKE OF EGGS AS MEASURED BY FOOD DIARIES

Taster Status	Taster Status	Mean Difference	Standard Error
Non-taster	Medium taster	-1.54*	0.60
	Supertaster	-0.64	0.65
Medium taster	Non-taster	1.54*	0.60
	Supertaster	0.89	0.46
Supertaster	Non-taster	0.64	0.65
	Medium taster	-0.89	0.46

* $p < 0.05$, two tailed

Unrestrained non-tasters, medium tasters and supertasters drank similar amounts of tea ($H = 0.907$, $df = 2$, $p > 0.05$) and coffee ($H = 3.571$, $df = 2$, $p > 0.05$). Based on Pillai's trace, there was no PROP effect on unrestrained eaters' intake of brown and white bread: $F(4, 146) = 0.563$, $p > 0.05$).

There were no clear patterns of intake between PROP taster groups among restrained eaters (Table 3.19). Restrained supertasters did however have the highest median instances of intake of coffee and white bread (Table 3.20).

TABLE 3.19
MEAN NUMBER OF INSTANCES OF INTAKE IN FOOD DIARIES FOR RESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters	Medium tasters	Supertasters
Cruciferous Vegetables	0.8 (1.10)	1.9 (1.89)	1.3 (0.96)
Non-cruciferous vegetables	10.0 (4.80)	19.1 (7.95)	21.5 (8.02)
High Fat Foods	15.0 (6.96)	14.8 (6.22)	16.0 (1.83)
Sweet Foods	22.4 (12.18)	28.3 (21.17)	33.0 (24.34)
Fat X Sweet	8.6 (6.58)	8.4 (5.52)	5.0 (1.83)
Citrus Fruit	2.0 (1.87)	4.3 (3.53)	0.8 (0.50)
Other Fruit	3.6 (7.50)	3.8 (3.63)	4.0 (4.83)
Dairy Products	15.6 (12.05)	16.7 (7.58)	17.8 (10.53)
Caffeine	0.4 (0.89)	8.0 (8.19)	9.3 (6.50)
Spicy Foods	2.8 (3.56)	1.7 (2.79)	2.3 (2.63)
Added Salt	5.2 (7.73)	3.8 (3.61)	3.8 (3.77)
Alcohol (units)	26.6 (29.48)	13.2 (14.86)	26.0 (22.32)
Milk	9.2 (7.98)	10.3 (6.22)	10.0 (7.87)
Eggs	0.2 (0.45)	1.3 (1.94)	2.3 (2.06)
Cheese	3.2 (1.30)	4.4 (2.64)	4.0 (0.82)
Butter	0.3 (0.58)	1.3 (1.86)	1.0 (1.73)
Margarine	3.7 (4.04)	5.3 (4.62)	1.7 (2.89)
Yoghurt	3.2 (4.55)	0.6 (0.86)	1.0 (2.00)

TABLE 3.20
MEDIAN NUMBER OF INSTANCES OF INTAKE IN FOOD DIARIES FOR RESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Median (Interquartile Range)		
	Non-tasters	Medium tasters	Supertasters
Coffee	0.0 (0.0)	0.0 (1.3)	6.5 (11.5)
Tea	1.0 (13.3)	6.5 (8.8)	2.5 (5.8)
Brown bread	2.8 (20.1)	5.0 (10.5)	2.0 (13.5)
White bread	4.5 (15.8)	6.5 (7.3)	14.0 (13.8)

3.4.7.2 Food Frequency Questionnaires

Unrestrained eaters with high PROP thresholds (i.e. low PROP sensitivity) reported more frequent consumption of several high fat foods, as well as the category of high fat foods, sweet foods, and foods high in both fat and sweet (Table 3.21). When frequency of consumption was correlated with PROP/NaCl ratios, unrestrained eaters with high PROP/NaCl ratios (i.e. high PROP acuity) consumed less bitter tasting coffee without sugar (and the caffeine category comprising tea and coffee), horseradish and gin (Table 3.22). They also reported eating white bread more frequently. It is interesting to note that among restrained eaters, there were no significant associations between PROP thresholds and reported frequency of intake of any of the 74 items. Intake of only three foods were significantly correlated with PROP/NaCl ratios: kale ($rho = 0.59, p < 0.05$) and Kohlrabi ($rho = 0.45$, $p < 0.05$) that very few participants had tried before, and white wine ($rho = 0.42$, $p < 0.05$). Although these findings suggest that there were more associations between PROP tasting ability and food intake for unrestrained than restrained eaters, it must be remembered that the restrained group was much smaller in size (n = 27, compared to N = 77).

TABLE 3.21
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP THRESHOLDS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES FOR UNRESTRAINED EATERS

Thresholds	Rho
Bacon	0.24*
Carrots	0.25*
Chips	0.36**
Dark chocolate	0.27*
Mayonnaise	0.27*
Spinach	-0.26*
Sunday roast	0.29*
Fat	0.40**
Sweet	0.23*
Fat & sweet	0.26*

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

TABLE 3.22
SPEARMAN'S RANK CORRELATION COEFFICIENTS BETWEEN PROP/NACL RATIOS AND FOOD FREQUENCY QUESTIONNAIRE RESPONSES FOR UNRESTRAINED EATERS

PROP/NaCl Ratio	Rho
Bacon	-0.23*
Coffee - no sugar	-0.32**
Gin	-0.23*
Horseradish	-0.32**
Parsnip	-0.24*
White bread	0.22*
Caffeine	-0.369**

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

3.4.8 PROP Taster Status and BMI/Dietary Restraint

BMI data were missing for two medium tasters. Thirteen percent of the women had BMIs less than 20 and were thus considered underweight, 72% had BMIs in the acceptable weight range (20 - 25), and 16% had BMIs greater than 25 and were therefore classed as either overweight or obese. The mean BMI of the whole sample was 23.0. There was a tendency for BMI scores to decrease with increasing PROP acuity (NTs>MTs>STs; Table 3.23), but this difference was not significant ($F[2, 99] = 0.83$, $p > 0.05$). Non-tasters had a mean BMI one point higher than that of medium tasters, who in turn were almost half a BMI point heavier than supertasters.

TABLE 3.23
MEAN BODY MASS INDEX ACCORDING TO PROP TASTER STATUS

	Mean BMI (SD)
Non-tasters	23.9 (5.9)
Medium tasters	22.9 (3.1)
Supertasters	22.5 (2.8)
Total	23.0 (3.6)

PROP taster status had no significant effect on dietary restraint scores ($F[2, 101] = 0.54$; $p > 0.05$). However, dietary restraint did significantly affect BMI, with restrained eaters (mean = 24.3 ± 3.8, N = 27) having a higher BMI than unrestrained eaters (mean = 22.5 ± 3.4, N = 75): $t(100) = -2.27$; $p<0.05$).

Although an inverse relationship between PROP sensitivity and BMI was found for both restrained and unrestrained eaters (Table 3.24), neither was significant: unrestrained eaters ($F[2, 72] = 0.27, p > 0.05$; restrained eaters: $F[2, 24] = 0.36, p > 0.05$).

TABLE 3.24
THE EFFECT OF PROP TASTER STATUS ON BMI FOR RESTRAINED AND UNRESTRAINED EATERS

	Mean (SD)	
	Unrestrained eaters (N = 77)	Restrained eaters (N = 27)
Non-tasters	23.2 (6.8)	25.6 (3.5)
Medium tasters	22.4 (2.5)	24.0 (4.0)
Supertasters	22.3 (2.6)	23.6 (4.2)
Total	22.5 (3.4)	24.3 (3.8)

3.4.9 Smoking

There were 33 smokers and 71 non-smokers in the sample. A higher percentage of non-tasters were smokers compared to medium tasters and supertasters (Table 3.25). Forty-four percent of non-tasters were smokers, compared to 30% of both medium tasters and supertasters. However this difference was not significant ($\chi^2 = 1.26$; $df = 2$; $p > 0.05$).

PROP taster status also had no significant effect on number of cigarettes smoked per day ($H = 1.66$: $df = 2$; $p > 0.05$; Table 3.26).

Smokers and non-smokers did not significantly differ in their PROP thresholds ($U = 1169.0, p > 0.05$) or their PROP/NaCl ratios ($U = 1150.0, p > 0.05$; Table 3.27).

TABLE 3.25
FREQUENCY OF SMOKERS AND NON-SMOKERS

	Smokers	Non-smokers
Non-tasters	7 (43.8%)	9 (56.3%)
Medium tasters	18 (29.5%)	43 (70.5%)
Supertasters	8 (29.6%)	19 (70.4%)

TABLE 3.26
PROP TASTER STATUS AND MEDIAN SELF-REPORTED NUMBER OF CIGARETTES SMOKED PER DAY

	Median (Interquartile Range)
	Number of cigarettes
Non-tasters	10 (9.0)
Medium tasters	7 (12.0)
Supertasters	10 (7.5)

TABLE 3.27
MEDIAN PROP THRESHOLD AND PROP/NACL RATIO FOR SMOKERS AND NON-SMOKERS

	Median (Interquartile Range)	
	Smokers	Non-smokers
PROP Threshold	5.7 (5.0)	6.5 (4.0)
PROP/NaCl Ratio	0.7 (0.75)	0.8 (0.9)

3.4.10 Extraneous Factors

Other factors besides smoking could affect PROP tasting ability, which in turn could potentially influence the relationship between this genetic factor and food choice. Only one individual wore a dental plate and two had had an x-ray in the previous two weeks, so these factors were not analysed any further. Participants with a previous head injury (defined as needing hospital treatment) had a slightly lower mean PROP threshold than those with no history of head trauma, but the same mean PROP/NaCl ratio (Table 3.28), neither of which was significantly different (thresholds: $t = -1.35$, $df = 102$, $p > 0.05$; ratio: $t = 0.01$, $df = 102$, $p > 0.05$). Present or past ear infection was associated with marginally heightened PROP perception but again these small differences were not significant (thresholds: $t = -0.81$, $df = 102$, $p > 0.05$; ratio: $t = 1.53$, $df = 70$, $p > 0.05$). Those with colds had a slightly lower mean threshold and a lower mean PROP/NaCl ratio than those without colds, indicating somewhat decreased perception, although these differences were not significant (thresholds: $t = 1.96$, $df = 100$, $p > 0.05$; ratio: $t = -1.06$, $df = 100$, $p > 0.05$).

TABLE 3.28
MEAN PROP THRESHOLDS AND PROP/NACL RATIOS ACCORDING TO PRESENCE/ABSENCE OF HEAD INJURIES, EAR INFECTIONS, AND COLDS

Pathology		Mean (SD)	
		PROP Threshold	PROP/NaCl Ratio
Head Injuries	Yes N = 13	5.5 (1.9)	1.2 (1.5)
	No N = 91	6.6 (2.8)	1.2 (1.6)
Ear Infections	Yes N= 51	6.2 (2.8)	1.4 (2.0)
	No N = 49	6.7 (2.7)	1.0 (0.9)
Colds	Yes N = 24	7.3 (2.6)	0.9 (1.2)
	No N = 78	6.1 (2.7)	1.3 (1.7)

3.4.11 Relationship between PROP Tasting and Age

There were no significant correlations between PROP threshold scores and age (r = -0.11, $p > 0.05$) or between PROP/NaCl ratios and age (r = -0.03, $p > 0.05$).

3.5 Discussion

3.5.1 PROP Tasting and Food Intake

PROP taste sensitivity had no effect on food intake as measured using seven-day food diaries in a sample of British women. Although PROP thresholds and NaCl ratios were significantly correlated with some items and categories of items in the food frequency questionnaire, these correlations were small and existed only for a small proportion of the 74 items, and visual inspection of the relevant scatterplots revealed no clear linear patterns. Many studies erroneously interpret small but statistically significant correlations as support for clear relationships. The sizes of the correlations were somewhat larger when the sample was divided into taster groups. However this may be attributable to the smaller size of these groups. Evidence for this interpretation comes from the fact that there tended to be higher associations for the smaller taster groups (non-tasters and supertasters) than among the larger group of medium tasters. Therefore it was concluded that PROP sensitivity also had little effect on food intake as measured by a food frequency questionnaire.

Different foods had significant correlations with threshold values than with PROP/NaCl ratios. This may reflect the fact that they measure different aspects of taste since threshold and suprathreshold measures often dissociate (Bartoshuk, 1978; Miller and Bartoshuk, 1991; Bartoshuk, Duffy, and Miller, 1994). An alternative interpretation of the discrepancy between these measures could be that the validity of the associations is weak. A number of associations would be expected to occur by chance when a large number of food items are examined even in the absence of any experimental effect.

The supertasters' significantly lower liking of the suprathreshold PROP solutions supports the classification of the taster groups. The fact that the three taster groups had similar hedonic ratings of NaCl also lends value to the use of sodium chloride as a standard. The similar responses to the salt questionnaire also supports this conclusion.

The finding that PROP sensitivity is not a genetic marker for food intake is consistent with previous studies (Mattes and Labov, 1989; Niewind, Krondl, and Shrott, 1988; Kaminski, Henderson, and Drewnowski, 2000; Jersza-Latta, Krondl, and Coleman, 1990; Lucchina et al. 1995; Lucchina, unpublished doctoral thesis; Ly and Drewnowski, 2001). The results of the present study using food diaries add validity to the literature which measured intake using food frequency questionnaires.

There are several possible explanations as to why there is no evidence for a PROP effect on food intake. Food intake is influenced by numerous factors (Shepherd, 1990) which may negate the influence of genetically mediated taste sensitivity. Any PROP effects could be negligible compared to all the other potential influences on consumption. For example, Steptoe et al. (1995) identified nine factors influencing food choice using factor analysis: health; mood; convenience; sensory appeal; natural content; price; weight control; familiarity and ethical concern. Furst et al. (1996) took a qualitative approach and noted the role of additional variables such as: life experiences (social, cultural, and physical environments the individual has been exposed to); context (physical and social environments in which food choices are made, including availability); ideals (i.e. "ideal" foods in terms of quality, health, and social status); resources (equipment, space, money, skills, knowledge, time); relationships (likes/dislikes and needs of others in the home). The converse, reasons why foods are rejected, rather than why foods are chosen, has also been explored. In constructing the Food Avoidance Inventory, Mooney and Walbourn (2001) identified five factors or sub-scales including weight, health, unnatural content, animal ethics, other/taste (availability, flavour and cost). Whereas men were most likely to reject foods due to taste/other reasons (followed by weight and health respectively) females rejected foods primarily for weight concerns (followed by health and ethical concerns). Since taste was not the dominant reason for women's rejection of particular foods, they may actually like the avoided food. Although both sexes gave similar ratings to the importance of sensory appeal in food *choice*, health reasons were equally important among the women (Steptoe et al., 1995). Since men report that taste is more important in their food choices/rejection than females, genetically-mediated PROP tasting ability may be more likely to influence males' foods rejections and possibly food choices than females'.

Masking of tastes may also negate potential PROP effects on food behaviours. Bitter tastes can be masked by the use of seasoning, dressings, sauces, sweeteners, or by cooking in oils. Therefore even foods perceived to taste very intense and/or unpleasant may still be eaten. For example although Ly and Drewnowski (2001) found that tasters gave higher bitterness ratings and lower hedonic ratings to caffeine solutions, the addition of a sweetener suppressed bitterness ratings more for tasters and eliminated the PROP effect on hedonic ratings. PROP taster status also did not affect reported consumption of coffee. This suggests that although PROP effects may be demonstrated with perception of laboratory preparations of a single food component, the influence of PROP acuity may be lessened in the choice of more complex foods and drinks.

3.5.2 The Potential Mediating Effect of Dietary Restraint and Pathology on Food Consumption and BMI

The effect of dietary restraint on food intake was investigated to determine whether it mediated any potential relationship between PROP tasting ability and food intake. High levels of restraint were weakly associated with lower reported consumption of high fat foods, high fat dairy products, tea, and white bread, and higher consumption of reduced calorie/low fat foods such as brown bread, cottage cheese, yoghurt, boiled potatoes, and diet cola. This finding is consistent with reports of weak negative correlations between dietary restraint and intake of high fat foods/caloric intake (Tuschl et al., 1990; Westenhoefer et al., 1990; de Castro, 1995; Klesges et al., 1992; Tepper et al., 1996). According to Legg et al. (2000), the weakness of the associations could be either because restraint has a consistent small effect on intake on all eating occasions or it has a larger effect on only some occasions than others which is levelled out when all instances of intake are aggregated.

Ear infections, head injury, and colds did not affect PROP acuity. Bartoshuk et al. (1996) found that participants with a history of otitis media (infection of the middle ear) displayed heightened perception to the taste of PROP, and those with a previous head injury exhibited decreased perception. No previous study has investigated the potential mediating role of restrained eating or pathology therefore future studies would be useful to see if the present finding holds and if other factors might be involved.

The potential effect of dietary restraint on the relationship between PROP acuity and BMI was also examined. Although non-tasters had the highest mean BMI and supertasters the lowest, this difference was not statistically significant. The same trend emerged when this analysis was applied to restrained and unrestrained eaters separately, but again it did not reach significance. Tepper and Ullrich (1999) found that supertasters had significantly lower BMIs than medium tasters and non-tasters among unrestrained eaters but not among restrained eaters. However their sample was much heavier and older than the present sample (mean BMI = 27.3, mean age = 38.0). The average participant was in the overweight range, whereas the average participant in the present sample was in the middle of the "normal" range (mean BMI = 23.0) and only 16% could be classed as overweight or obese. A negative correlation was also found between PROP perception and BMI among older overweight adults (65-95 years, mean BMI = 27.97; $r = -0.29$; Lucchina et al., 1995; Lucchina, unpublished doctoral thesis, 1995). Other studies with young normal weight women reported no significant PROP effects (Drewnowski, Henderson and Shore, 1997a, 1997b; Drewnowski, Henderson and Barratt-Fornell, 1998; Smagghe and Louis-Sylvestre, 1998; Kaminski et al., 2000; Ly and Drewnowski, 2001).

The finding that restrained eaters had higher BMIs than unrestrained eaters is consistent with previous studies (Klesges et al., 1992; Klem et al., 1990; Ruderman, 1986; Tepper et al., 1996). At face value it seems incongruous that restrained eaters are heavier despite the associations between high restraint scores and decreased intake of low fat foods. However, such a set of relationships has been identified previously (Klesges et al., 1992), the associations were weak, and could reflect dieting behaviour of heavier individuals. Alternatively the more overweight individuals (and restrained) may have under-reported their intakes, perhaps for social desirability reasons. Groups exhibiting high dietary restraint have been found to report lower energy intake than groups with lower levels of restraint (Laessle et al., 1989; Bingham et al., 1995; Kretsch et al., 1999). Mela and Aaron (1997) similarly found that restrained eaters were significantly more likely to alter their eating behaviour when completing food records than unrestrained eaters, even among only normal weight individuals. Since restrained eaters were a minority in the sample, and similar findings were produced when unrestrained individuals' data were analysed separately as when combined with those of restrained eaters, potential under-reporting among restrained eaters was thought not to be problematic in the current study.

3.5.3 Smoking

A higher proportion of non-tasters were smokers than medium tasters or supertasters but this difference was not statistically significant. Smokers and non-smokers did not differ in their PROP tasting ability, and PROP taster status had no effect on number of cigarettes smoked. However, there were only 33 smokers which may have restricted the chances of identifying a PROP effect. Few effects of PROP tasting on smoker status have been reported in the existing literature, although these studies were carried out several decades ago and used unrefined methods of measuring PROP perception (Salmon and Blakeslee, 1935; Falconer, 1947; Krut et al., 1961; Koch and Nesarajah, 1966; Pons, 1955; Akesson, 1959; Cunha and Abreu, 1956; Freire-Maia and Quelce-Salgado, 1960; Fischer et al., 1963). Kaplan et al. (1964) however found significantly more tasters among non-smokers than heavy smokers, and Thomas and Cohen (1960) reported an effect in the opposite direction: smokers were significantly more sensitive to PTC than non-smokers.

In a recent study of liking/disliking of the taste of cigarettes, supertasters liked the taste of cigarettes significantly less than the non-tasters (Freeman et al., 2001). We concluded that PROP effects may be more likely to be identified when liking/disliking of taste is studied rather than the behavioural measure of intake.

3.5.4 Summary/Conclusion

It has previously been speculated that if PROP acuity serves as a genetic marker for food choice, there would be implications for programmes that promote dietary change (Drewnowski and Rock, 1995). These programmes tend to emphasise nutritional education and behavioural change and overlook the role of taste. However the results of the present study provide no evidence that this genetically mediated taste factor influences food selection. It is possible that PROP perception may be more influential in food rejection than food choice and further study would be useful to examine this. Further study of the role of PROP acuity in men's food choices as well as food rejection would also be of interest.

Chapter Four

The Effect of Genetically Mediated Taste Acuity for 6-N-Propylthiouracil (PROP) on Food Likes/Dislikes

4.1 Abstract

The majority of studies of the effects of PROP tasting ability on food likes/dislikes have used preference questionnaires or laboratory preparations of a single taste quality. Food preference questionnaires are limited to measuring attitudes to food names, rather than actual sensory responses to foodstuffs, and responses to test solutions may not reflect responses to real foods with more complex tastes. In the present study, 98 females tasted cheddar cheeses (mild, medium, extra mature, and low fat), milks (full fat, semi-skimmed, and skimmed), cruciferous and non-cruciferous vegetables (broccoli, Brussels sprouts; parsnips, carrots, and spinach), and orange and grapefruit juices. They placed their hedonic ratings on 100 mm line scales anchored with "like extremely" and "dislike extremely". A food preference questionnaire was included for comparison. There were no significant relationships between PROP taster status and actual or reported food likes/dislikes.

4.2 Introduction

Several studies have found that individuals with a high sensitivity to PROP had more food dislikes than less sensitive individuals in food preference questionnaires (Fischer et al., 1961; Fischer and Griffin, 1961; Glanville and Kaplan, 1965a; Jefferson and Erdman, 1970; Drewnowski, Henderson, Shore, and Barratt-Fornell, 1998; Goldsmith and Kanarek, 2001). Bauer and Utermohlen (1999) found that although supertasters rated the greatest number of foods as "very bad" (i.e. disliked), it was the medium tasters who gave the highest hedonic ratings to the list of food names. The effect of taster status on liking for specific foods and food groups has also been investigated. Food groups studied include fruit and vegetables, caffeine, dairy products, and high fat and high sweet foods.

Drewnowski, Henderson, and Shore (1997b) examined whether the acceptance of grapefruit juice is influenced by sensitivity to PROP. Supertasters were found to dislike grapefruit juice (questionnaire item) and the taste of naringin (the principal bitter ingredient in grapefruit juice) solutions significantly more than non-tasters. However, there was no PROP effect for oranges or orange juice, lemons or apples or "a variety of other vegetables and fruit" listed in a food preference questionnaire. Glanville and Kaplan (1965a; questionnaire) and Duffy et al. (2001; measure of preference unspecified) also found that non-tasters liked grapefruit juice more than tasters. Data collected by Smagghe and Louis-Sylvestre (1998) are inconsistent with these findings. They found that hedonic ratings of tasted naringin solutions were independent of taster status. However this study had several methodological flaws including the use of a category scale with a ceiling effect which may have negated potential PROP effects.

Jefferson and Erdman (1970) found that PTC sensitive individuals disliked turnip greens and beets significantly more than less sensitive individuals. However, tasters' and non-tasters' ratings of the other fifty-two foods in the checklist of food names did not differ.

Two studies looked at hedonic ratings based on tasting of fruits and vegetables in children. Anliker et al. (1991) conducted a study with 34 children aged five to seven with the expectation that their food likes/dislikes should be least biased by health beliefs and nutritional considerations. Whilst they found no significant differences in the taster group's liking for raw and cooked broccoli (and spinach and bananas), Keller et al. (1999) found that non-taster girls liked raw broccoli significantly more than taster girls, although this effect was not seen in boys. Keller et al. reported no significant effects for cooked broccoli, orange or grapefruit juice.

Niewind, Krondl, and Shrott (1988) studied older adults ranging in age from 55 to 70 (mean age = 63) years. They reported that tasters and non-tasters did not differ in their liking of both raw and cooked cabbage (based on actual tasting), although the tasters rated cooked cabbage as having significantly more flavour than did the non-tasters.

Tepper (1998) suggested a possible reason why some studies did not find a relationship between PROP taster status and liking of vegetables. She stated that aversion to vegetables may be due to factors other than their bitter taste, and these could overshadow the influence of PROP sensitivity on the outcome of these studies. These factors included the vegetable's appearance or texture, social or cultural taboos associated with eating them, or unpleasant gastrointestinal effects of ingestion for some people.

Several studies have examined PROP effects on hedonic ratings of dairy products. Cheese was ranked higher in order of preference and milk ranked lower by non-tasters than by tasters (Anliker et al., 1991). The same pattern was found using a five-point facial hedonic rating measure, although the results were not significant. Tasters' hedonic scores on a food preference questionnaire were lower than the non-tasters' for sixty foods and beverages, although these differences were not significantly different.

Forrai and Bankovi (1984) studied food likes amongst 98 pairs of monozygotic twins. They found that PTC non-tasters liked whipped cream and strong tasting curded Ewe-cheese more than tasters did. No mention was made of other dairy products in the list of 69 foods. They determined PTC taster status using only a single solution, although they argued that this concentration was found to be the antimode in the distribution of thresholds in their earlier investigations.

Very few studies have examined liking of for caffeine or foods and drinks containing caffeine. Smagghe and Louis-Sylvestre (1998) found that hedonic ratings of caffeine solutions were not influenced by taster status. Although Ly and Drewnowski (2001) also used a category scale to measure PROP acuity, they found that tasters liked caffeine solutions less than non-tasters. However, when a sweetener (neohesperidin dihydrochalcone) was added there was no longer a PROP effect on hedonic responses. The authors concluded that sweetening of caffeine minimises the impact of genetic taste differences, and that masking bitter tastes with sweeteners or fats may limit the impact of PROP tasting ability on food choice. It cannot be assumed that liking/disliking of solutions of caffeine reflects responses to actual beverages containing caffeine such as coffee. Duffy et al. (2001) found that individuals with heightened PROP perception reported decreased liking of coffee (though it is unclear whether coffee was actually tasted).

Akella, Henderson, and Drewnowski (1997) tested the hypothesis that PROP medium tasters and supertasters would be more likely to reject Japanese green tea and various soy products (tofu, miso, and plain and vanilla flavoured soya milk) than non-tasters. The participants tasted five different concentrations of green tea and the range of soy products and gave intensity and hedonic ratings on nine-point category scales. Heightened sensitivity to PROP was related to increased dislike of green tea and plain tofu and increased liking for flavoured soya milk. No PROP effects were identified for miso or plain soya milk.

Several recent studies have examined non-tasters', medium tasters' and supertasters' liking for fat. The medium tasters and supertasters tested by Tepper and Nurse (1997a) expressed no preference for either low or high fat dressings that were tasted, although the non-tasters preferred the high fat version (Tepper and Nurse, 1997b). Lucchina et al. (1995) used verbally administered questionnaires to study food likes/dislikes amongst a group of older females aged between 65 and 95. There was a positive association for self-reported eating enjoyment. Liking of high fat foods decreased with increasing PROP tasting ability in females but not in males (Bartoshuk et al., 1999b).

Tuorila et al. (1997) found that although the pleasantness ratings of low fat cream cheese samples (10% fat) were quite similar for all taster groups, "high tasters" (presumably equivalent to supertasters) rated the pleasantness of high fat samples (40% fat) higher than non-tasters. This direction of effect for the high fat cream cheeses is opposite to what would be expected. Decreased liking of high fat foods among individuals with heightened PROP acuity would be predicted. However the unexpected finding could be attributable to the fact that high tasters also gave lowest bitterness ratings to the high fat samples, but the highest bitterness ratings to the low fat cream cheeses. Fat may have had a suppressing effect on perception of bitter, with high tasters having heightened acuity to fat and thus decreased perception of bitterness than non-tasters, which is more palatable.

Liking of sweet tastes has received a great deal of research attention. Looy and Weingarten (1992) classified individuals whose hedonic ratings for sucrose solutions increased with increasing sweetness as sweet "likers", and those whose hedonic responses decreased with increasing sweetness as sweet "dislikers". They found that for both adults and children, PROP non-tasters tended to be sweet likers, whereas PROP tasters were almost always sweet dislikers. Sweet dislikers perceived a very pure sweet sensation in sucrose solutions whereas sweet likers perceived a more complex taste including non-sweet components. Looy and Weingarten hypothesised that PROP tasters' and non-tasters' different perceptions of sweet substances may influence their liking of sweet tastes.

Although Drewnowski Henderson, and Shore (1997b) found no relationship between PROP taster status and liking of sweet they replicated the finding that sucrose dislikers tended to perceive sucrose solutions as slightly more sweet. They suggested that the discrepancy between the main findings could be due to gender and to the stimuli used. Looy and Weingarten's (1992) sample comprised both males and females (29% males, 71% females) whereas all of Drewnowski et al.'s participants were female. Liking of sweet taste is reported to depend upon gender and degree of concern with weight (Drewnowski, 1987). It was also suggested that PROP taster status may be better related to preference for mixtures of sugar and fat than sucrose solutions.

Duffy, Weingarten, and Bartoshuk (1995) studied the association between sensitivity to PROP and liking of sweet and high fat foods in a sample with roughly equal numbers of males and females. Participants gave hedonic ratings to 82 foods/beverages in a food preference questionnaire which were categorised into high fat sweets, low fat sweets, all sweets, added fat, and high fat foods. PROP tasters liked all sweet and high fat foods less than non-tasters. However when restrained eaters were removed the difference was no longer significant for high fat sweets (e.g. chocolate, cake).

Drewnowski, Henderson, and Barratt-Fornell (1998) examined the relationship between PROP taster status and hedonic response to sugar/fat mixtures in foods and beverages that were actually tasted. The stimuli were milk (3.5% fat), "half-and-half" (10.5% fat), and heavy cream (30% fat), each sweetened with 2%, 4%, 8%, 16% and 32% sucrose. Although supertasters liked the sugar/fat mixes better than non-tasters or medium tasters these differences were not statistically significant. No differences have been reported between tasters and non-tasters likings of white milk and dark chocolate, chocolate milk drinks, or vanilla puddings (Ly and Drewnowski, 2000; Yackinous and Guinard, 2001).

The relationship between PROP tasting ability and food likes/dislikes differs for males and females. Monneuse, Bellisle and Louis-Sylvestre (1991) found that women preferred a sucrose level of 10% in soft white cheese and heavy cream stimuli, whereas men preferred an optimal level of 20%. Data collected by Duffy and her colleagues (Duffy, Weingarten, and Bartoshuk, 1995; Duffy, Bartoshuk, and Weingarten, 1995) support this finding. They found that female supertasters' hedonic ratings of high fat and low-fat sweets were lower than those of female non-tasters, whereas male supertasters showed greater liking than male non-tasters.

Duffy and Bartoshuk (1996b) examined a wider range of foods. The 82 item food preference questionnaire comprised a range of strong tasting foods and foods with varying fat content. The female participants primarily accounted for the associations between higher fungiform papillae density and increased liking of bitter and non-bitter vegetables and decreased liking for low-fat sweets and salt. Males with increased fungiform papillae densities gave higher hedonic ratings to fats and bitter cheeses than men with lower densities, whereas women with increased fungiform papillae densities gave lower ratings to low-fat milk. Similar trends were found when suprathreshold

PROP responses were taken as the measure of genetic taste sensitivity. Increased PROP acuity was associated with lower hedonic ratings of foods high in both fat and sweet, and showed sex differences. Women with heightened PROP tasting ability reported decreased liking for both high-fat and low-fat sweets. Men, on the other hand, gave higher hedonic ratings to low-fat sweet items.

Sex differences in food likes/dislikes may not be solely due to differing sensory abilities. Preoccupation with weight and body image in females in the western world may also be involved. This may lead to negative attitudes toward foods believed to be "fattening" and/or dislike of their sensory properties. Duffy, Weingarten, and Bartoshuk (1995) measured dietary restraint and found that removing restrained eaters from the analysis negated the significance for high-fat sweets but not for low fat-sweets, all sweets, added fat, or high-fat foods. This raises the question of whether measures of liking/disliking of taste are generating responses based on pleasure sensation or cognitive/attitudinal judgements of foods.

Most of the research investigating the relationship between PROP taster status and food likes/dislikes has studied responses to food preference questionnaires or to laboratory solutions rather than to actual tasting of real foods. Hedonic ratings of stimuli such as sucrose solutions may not predict liking for more complex sweet foods. Food preference questionnaires measure recollection of liking for a certain food or type of food and attitudes to food names rather than actual taste experience. In the present study, hedonic and sensory responses to tasting of real foods will be used.

4.3 Method

4.3.1 Participants

The participants were 98 female students and staff at Aston University in Birmingham, England. They ranged in age from 18 to 42, with a mean age of 22.1 years, SD: 6.0; age information not available for one participant. Thirty-four women were smokers, and sixty-three were non-smokers. Mean body mass index for the sample was 23.3, SD = 4.1 (range = 17 – 42) which falls in the acceptable weight range (20 - 25).

All participants were instructed not to eat, drink (water was allowed), smoke, chew gum or brush their teeth for at least an hour before their appointment.

4.3.2 Materials

4.3.2.1 Stimuli

All stimuli used to determine taster status were the same as those used in Chapter Three (see Section 3.3.2.1).

The fourteen foods and drinks that served as taste stimuli included several types of: 1) cheese (Tesco's own brand mild, mature, extra mature, and low fat cheddar); 2) milk (full fat, semi-skimmed, and skimmed); 3) vegetables (broccoli, Brussels spouts, carrots, parsnips, spinach); 4) fruit juice (Londis' own brand orange juice and unsweetened grapefruit juice). Filtered tap water was used as an interstimulus rinse. The fruit juices were bought in cartons rather than squeezed. All of the vegetables were bought fresh, except the spinach which was bought frozen because it was more amenable to microwave oven cooking.

4.3.2.2 Questionnaires

The participants completed the dietary restraint, salt intake, and background information questionnaires used previously in Chapter Three (Section 3.3.2.3), as well as a food preference questionnaire (Appendix Five). 100 mm horizontal line scales were used to measure liking for a list of 76 foods and drinks, with two anchors, "not at all" on the left and "extremely" on the right. This measure was employed to enable comparison between actual and reported hedonic responses. The list of foods was based on a food preference questionnaire used by Freeman (unpublished data) and comprised mainly strong tasting foods, and some blander items.

4.3.3 Procedure

The data were collected from each participant over two sessions on two separate days. During the first session informed consent was obtained, taste tests were carried out to determine PROP taster status, the questionnaires were completed, and height and weight measured. Sensory responses to the tasted food items were measured during the second session, after which the participants were debriefed. These sessions took approximately 60 minutes and 30 minutes respectively.

4.3.3.1 Determination of PROP Taster Status

PROP taster status was determined using the same procedures as in Chapter Three (Sections 3.3.3.1 and 3.3.3.2).

4.3.3.2 Food Like/Dislikes

Each time an item was tasted, the participant was asked to rate how much she liked it, as well as how bitter, and fatty (apart from the vegetables and fruit juices) she thought it was. Participants were instructed to drink filtered water between each sample in sufficient quantity to remove any taste that may have remained. There was an interval of approximately 45 seconds between presentations of samples.

The categories of foods were presented in a specific order to minimise lingering tastes of the stronger tasting foods influencing following sensory responses. The order was milks, cheeses, vegetables and fruit juices. This allowed time for the taste of the stronger cheeses to fade and be rinsed away whilst the vegetables were heated, and enabled the grapefruit juice to be presented last. The presentation of the items within the groups of cheeses, milks, and vegetables was randomised, though the orange juice was always presented before the grapefruit juice.

All foods and drinks were tasted once and were swallowed. The milks, cheeses, and fruit juices were served at 5°C (refrigerator temperature), whereas the vegetables were cooked in a microwave oven and served warm as they would be served in everyday eating situations. The drinks were presented in disposable shot glasses and the vegetables individually on a small plate. Cheeses were presented as approximately 2cm cubes, and milks and juices in approximately 20ml quantities. Vegetable servings were approximately 15g. The different types of cheeses and milks were not identified to the participant to prevent cognitive bias, although when the general identity of a food was not clear the participant was told what it was before it was tasted (usually in the cases of parsnip, spinach and grapefruit juice).

4.3.4 Statistics

One-way between subjects MANOVA analyses (using Pillai's criterion) were used to examine the effect of PROP taster status (non-tasters, medium tasters, and supertasters) on hedonic, bitterness and fattiness ratings of the cheeses, milks, vegetables, and fruit juices that were tasted. For clarity, unless otherwise stated all univariate and stepdown F values were not significant and are not reported. MANOVA analyses were repeated for foods in the food preference questionnaire that were also tasted to enable comparison between the self-report and sensory methods of measuring food likes/dislikes. Pearson's correlations were also used to assess associations between PROP acuity and hedonic ratings of items in the food preference questionnaire. These analyses were repeated for restrained and unrestrained eaters separately.

Pearson's correlations were also used to examine the associations between 1a) hedonic and bitterness ratings, 1b) hedonic and fattiness ratings, and 1c) bitterness and fattiness ratings as well as between 2a) hedonic ratings based on tasting and hedonic responses based on questionnaires. Kendall's tau was used to explore the relationships between 2b) food intake (as measured by the FFQ) and taste likes/dislikes, and 2c) intake and reported likes/dislikes since responses to the FFQ were measured on an ordinal scale.

The effect of PROP taster status on body mass index (BMI) was examined using a one-way between subjects ANOVA, which was repeated again for restrained and unrestrained eaters separately.

A Chi-square test was used to investigate differences in smoker status between non-tasters, medium tasters, and supertasters. Differences in the number of cigarettes smoked by the three taster groups were analysed using a Kruskal-Wallis test. Mann-

Whitney was employed to determine whether smokers and non-smokers differed in their PROP tasting ability. Independent t-tests were used to test for differences in PROP thresholds and suprathreshold responses between individuals with and without various pathologies (e.g. colds, ear infections, head injuries).

4.4 Results

4.4.1 Frequencies of Non-tasters, Medium Tasters, and Supertasters

There were 15 non-tasters, 51 medium tasters, and 32 supertasters (NTs = 15%, MTs = 52%, STs = 33%). All three taster groups were similar in age: $H = 2.67$; $df = 2$; $p > 0.05$. The distribution of PROP thresholds resembles the general bimodal distribution with an antimode at solution 9 (0.0001 mol/litre PROP; Figure 4.1).

4.4.2 PROP/NaCl Liking

Liking of PROP and NaCl solutions decreased with increasing concentration (1 = like extremely, 9 = dislike extremely) for all three taster groups (Figures 4.2 and 4.3). Supertasters disliked the suprathreshold PROP solutions more than medium tasters, and the medium tasters in turn disliked them more than the non-tasters. This difference was significant for the four strongest solutions (all *H*s > 9.26; all *p*s < 0.01) but not the lowest concentration ($H = 3.04$, $df = 2$, $p > 0.05$).

In contrast to the hedonic ratings to PROP solutions, PROP taster status had no significant effect on liking of all five NaCl solutions (all *H*s < 2.59; all *ps* > 0.05).

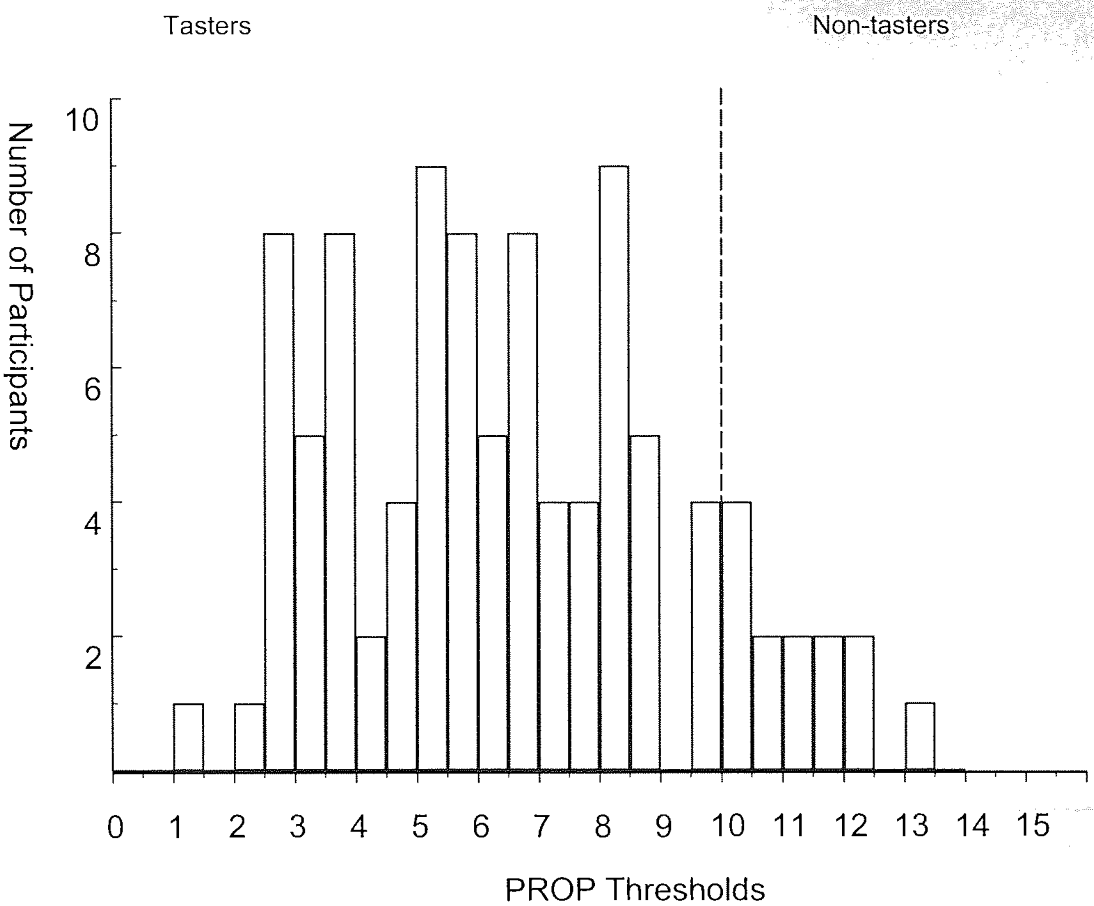

FIGURE 4.1
DISTRIBUTION OF PROP THRESHOLDS

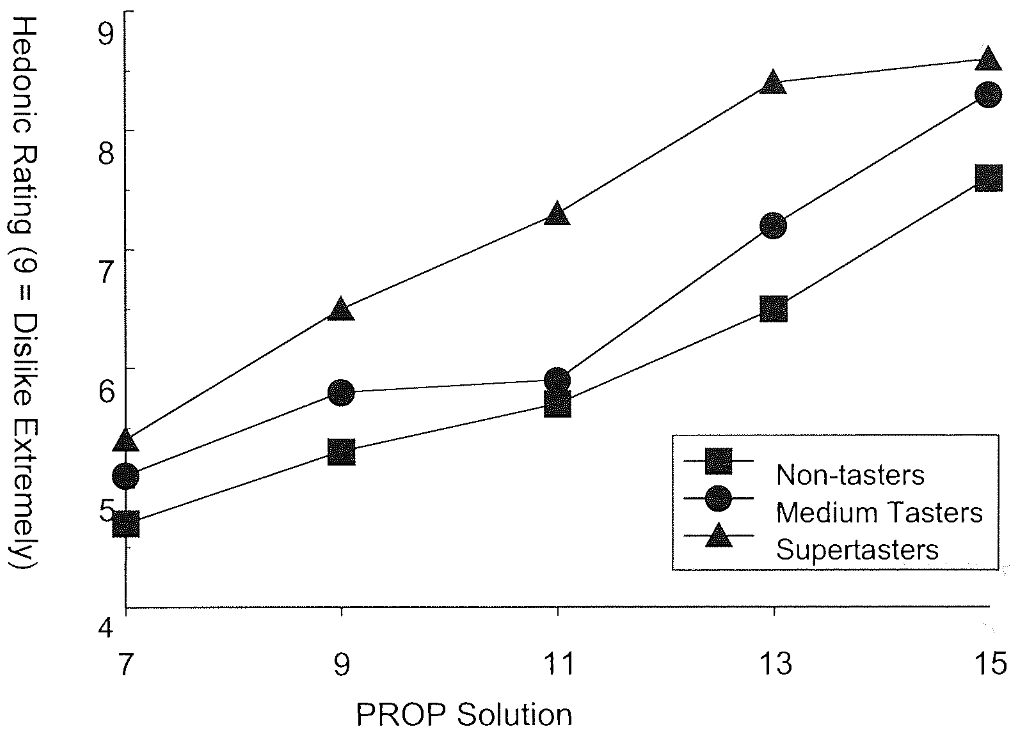

FIGURE 4.2
HEDONIC RATINGS OF PROP SOLUTIONS AS A FUNCTION OF PROP CONCENTRATION

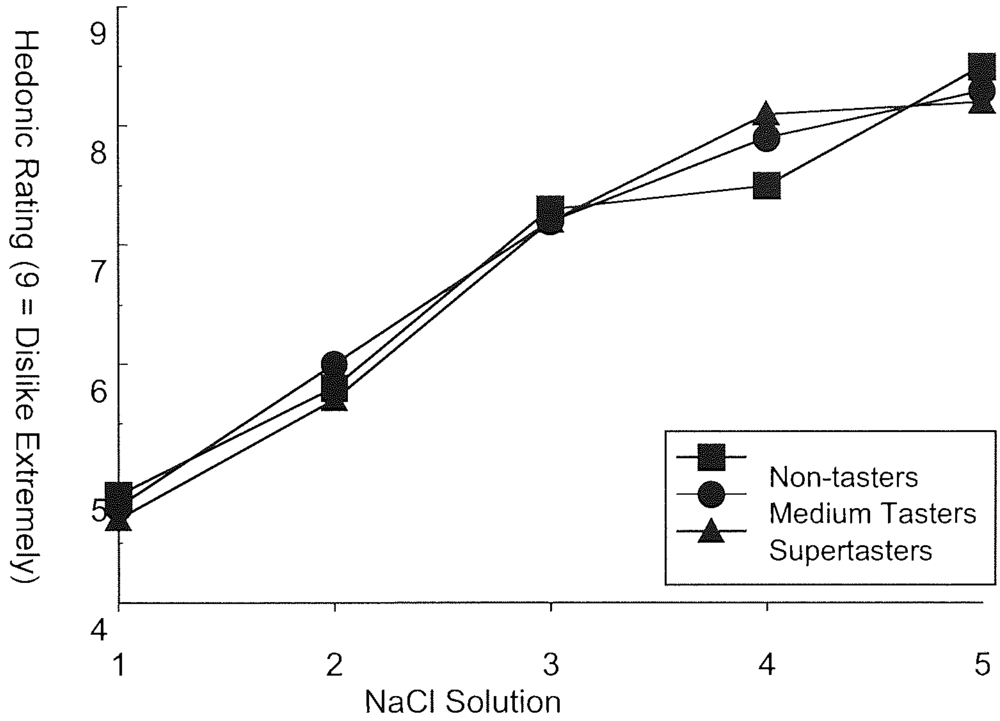

FIGURE 4.3
HEDONIC RATINGS OF NACL SOLUTIONS AS A FUNCTION OF NACL CONCENTRATION

4.4.3 Relationship between Hedonic, Bitterness Ratings, and Fattiness Ratings

TABLE 4.1
PEARSON'S CORRELATION COEFFICIENTS HEDONIC RATINGS AND BITTERNESS AND FATTINESS RATINGS

	Bitterness Ratings	Fattiness Ratings
Mild cheddar	-0.09	0.19
Mature Cheddar	-0.30**	0.15
Extra Mature Cheddar	-0.32**	0.14
Low Fat Cheddar	-0.37**	0.03
Full fat milk	-0.44**	0.01
Semi-skimmed milk	-0.26*	-0.07
Skimmed Milk	-0.27**	0.10
Parsnip	-0.25*	N/A
Brussels Sprouts	-0.18	N/A
Spinach	-0.13	N/A
Broccoli	-0.35**	N/A
Carrot	-0.34**	N/A
Orange juice	-0.30**	N/A
Grapefruit juice	-0.44**	N/A

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

There were negative associations between hedonic ratings and bitterness ratings of all food items that were tasted (-0.25 to -0.44; Table 4.1). The greater the perceived bitterness rating of a food, the less it was liked. Or, since we cannot assume causality, disliked foods may have been rated as more bitter. Although most of the correlations between hedonic and bitterness ratings were significant, they were small, indicating that the associations were weak.

Correlations between hedonic and fattiness ratings were not significant and generally positive, ranging from 0.01 to 0.19 (Table 4.1). Correlations between bitterness and fattiness ratings (not tabulated) were also extremely small (-0.02 to -0.16), not significant, and not uniformly positive or negative.

4.4.4. PROP Taster Status and Food Likes/Dislikes

4.4.4.1 Hedonic Ratings Based on Actual Tasting of Foods

TABLE 4.2
NON-TASTERS', MEDIUM TASTERS', AND SUPERTASTERS' MEAN HEDONIC RATINGS (BASED ON ACTUAL TASTING OF FOODS)

	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Mild Cheddar	66 (25.6)	64 (28.6)	64 (27.1)
Mature Cheddar	62 (31.7)	56 (29.3)	66 (27.0)
Extra Mature Cheddar	48 (31.2)	43 (31.8)	51 (28.8)
Low Fat Cheddar	34 (26.3)	38 (28.7)	45 (29.6)
Whole Milk	58 (30.7)	56 (30.2)	49 (31.8)
Semi-skimmed	49 (29.9)	56 (29.8)	61 (28.9)
Skimmed	37 (32.0)	43 (30.1)	42 (32.5)
Broccoli	45 (22.2)	57 (31.2)	61 (31.3)
Brussels sprouts	37 (24.3)	44 (31.3)	42 (34.1)
Carrot	65 (19.3)	64 (32.5)	68 (28.0)
Parsnip	37 (29.1)	46 (31.0)	52 (32.4)
Spinach	17 (16.6)	40 (29.5)	43 (32.3)
Orange Juice	86 (13.6)	84 (15.7)	79 (23.4)
Grapefruit Juice	31 (27.2)	40 (36.9)	33 (35.5)

All three PROP taster groups gave similar hedonic ratings to mild cheddar cheese (Table 4.2). Supertasters gave slightly higher hedonic ratings to mature, extra mature, and low-fat cheddar cheeses than non-tasters and medium tasters. MANOVA analyses showed that taster status did not have a significant multivariate effect on liking of cheddar cheeses that vary in strength and fat content ($F[8, 186] = 0.57; p > 0.05$).

Supertasters had a lower mean hedonic rating for whole milk than non-tasters and medium tasters. Conversely, non-tasters' had the lowest mean hedonic rating for both semi-skimmed and skimmed milk. PROP taster status did not have a significant multivariate effect on liking of the three types of milk with varying fat content ($F[6, 184] = 0.94; p > 0.05$).

Non-tasters had the lowest mean hedonics rating for all of the vegetables, with the exception of carrots where all three taster groups had similar ratings. However PROP taster status did not have a significant multivariate effect on liking of cruciferous and non-cruciferous vegetables ($F[10, 184] = 1.12; p > 0.05$).). Only the stepdown F value for spinach was significant at an alpha level of 0.05 ($F[2, 95] = 4.50, p < 0.05$). However since the univariate F value for spinach was not significant, it is perhaps best to interpret the descriptive statistics. Non-tasters mean hedonic rating was lower than those of medium tasters and supertasters (Table 4.2).

Supertasters had a slightly lower mean hedonic rating for orange juice than non-tasters and medium tasters. Medium tasters had the highest mean hedonic rating for unsweetened grapefruit juice. MANOVA analyses showed that taster status did not have a significant multivariate effect on liking of orange or grapefruit juice ($F[4, 190] = 0.68; p > 0.05$).

4.4.4.2 Hedonics Ratings Measured Using a Food Preference Questionnaire (FPQ)

TABLE 4.3
NON-TASTERS', MEDIUM TASTERS', AND SUPERTASTERS' MEAN HEDONIC RATINGS (MEASURED USING A FOOD PREFERENCE QUESTIONNAIRE)

	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Mild Cheddar	67 (28.9)	66 (29.8)	65 (27.0)
Mature Cheddar	71 (27.6)	59 (31.5)	65 (29.2)
Extra Mature Cheddar	49 (31.6)	51 (34.0)	53 (33.7)
Low Fat Cheddar	51 (29.2)	61 (26.9)	59 (25.6)
Whole Milk	49 (33.5)	36 (31.2)	45 (34.2)
Semi-skimmed	68 (26.4)	64 (29.8)	64 (27.1)
Skimmed	48 (32.0)	44 (33.0)	44 (34.0)
Broccoli	61 (26.1)	66 (31.5)	68 (27.1)
Brussels sprouts	43 (30.7)	35 (33.7)	42 (37.1)
Carrot	72 (17.4)	67 (27.9)	66 (25.1)
Parsnip	47 (26.2)	54 (31.4)	54 (32.3)
Spinach	37 (31.8)	48 (34.2)	44 (29.7)
Orange Juice	81 (18.4)	81 (20.6)	81 (19.8)
Grapefruit Juice	47 (26.9)	41 (34.0)	32 (35.4)

All three taster groups gave similar hedonic ratings to mild cheddar cheese, and extra mature cheddar cheese (Table 4.3). Non-tasters had the highest mean hedonic rating for mature cheddar cheese, with medium tasters having the lowest mean score. Medium tasters and supertasters had slightly higher mean hedonic ratings for low at cheddar cheese than the non-tasters. MANOVA analyses showed that taster status did not have a significant multivariate effect on liking/disliking of any of the cheeses in the food preference questionnaire ($F[8, 140] = 0.91; p > 0.05$).

Medium tasters had the lowest mean hedonic rating for whole milk. Non-tasters had marginally higher mean hedonic rating for both semi-skimmed and skimmed milk than medium tasters and supertasters. However PROP taster status did not have a significant multivariate effect on liking/disliking of any of the milks in the food preference questionnaire ($F[6, 178] = 0.44; p > 0.05$).

Non-tasters had the lowest mean hedonic ratings for broccoli, parsnips, and spinach, and the highest mean hedonic rating for carrot. Medium tasters had a slightly lower hedonic rating for Brussels sprouts than non-tasters and supertasters. PROP taster status did not have a significant multivariate effect on liking/disliking of any of the vegetables in the food preference questionnaire that had also been tasted ($F[10, 156] = 0.61; p > 0.05$).

All three taster groups gave similar mean hedonic ratings for orange juice, whereas supertasters disliked unsweetened grapefruit juice the most, and non-tasters the least. MANOVA analyses showed that taster status did not have a significant multivariate effect on liking/disliking of orange and grapefruit juice in the food preference questionnaire ($F[4, 190] = 0.64; p > 0.05$).

Correlations between PROP thresholds and self-reported food likes/dislikes measured by the food preference questionnaire ranged from -0.003 to 0.25. There were statistically significant correlations for only two food items: chips ($r = 0.21$, $p < 0.05$) and horseradish ($r = 0.25$, $p < 0.05$). Reported liking of these foods increased with decreasing PROP sensitivity.

Few associations were found when PROP/NaCl ratios were used as a measure of PROP tasting ability. Correlations ranged from 0.007 to 0.32, with significant associations for chips ($r = -0.24$, $p < 0.05$), margarine ($r = -0.24$, $p < 0.05$), and plain soya milk ($r = 0.32$, $p < 0.05$). Intake of chips and margarine decreased and intake of soya milk increased with increasing PROP acuity.

4.4.5 PROP Taster Status and Bitterness Ratings

TABLE 4.4
NON-TASTERS', MEDIUM TASTERS', AND SUPERTASTERS' MEAN BITTERNESS RATINGS

	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Mild Cheddar	24 (26.0)	24 (25.1)	22 (24.4)
Mature Cheddar	39 (29.9)	42 (28.6)	25 (29.3)
Extra Mature Cheddar	41 (27.3)	36 (27.9)	35 (32.1)
Low Fat Cheddar	37 (30.3)	40 (29.2)	36 (31.6)
Whole Milk	16 (15.3)	11 (15.2)	13 (19.2)
Semi-skimmed	15 (15.7)	15 (20.3)	11 (15.7)
Skimmed	27 (27.3)	17 (22.7)	16 (21.4)
Broccoli	34 (29.5)	29 (28.4)	30 (27.1)
Brussels sprouts	35 (26.6)	38 (30.0)	45 (28.6)
Carrot	21 (19.5)	16 (22.9)	17 (22.3)
Parsnip	21 (22.3)	18 (20.8)	31 (31.1)
Spinach	36 (29.6)	30 (28.8)	33 (29.3)
Orange Juice	46 (23.4)	33 (23.5)	28 (26.7)
Grapefruit Juice	86 (13.5)	83 (18.7)	89 (9.6)

All three taster groups gave similar bitterness ratings to mild, extra mature, and low fat cheddar cheeses (Table 4.4). Supertasters had the lowest mean bitterness rating of mature cheddar cheese. MANOVA analyses showed that PROP taster status did not have a significant multivariate effect on bitterness ratings of the cheddar cheeses with variable strengths ($F[8, 184] = 1.09$; $p > 0.05$). Only the stepdown F value for mature cheddar was significant ($F[2, 95] = 3.40$, $p < 0.05$). Since the univariate F statistic was not significant, there was no PROP effect on the bitterness ratings of mature cheddar.

Non-taster, medium tasters, and supertasters had similar mean bitterness ratings for whole and semi-skimmed milks. Non-tasters' mean bitterness rating of skimmed milk was slightly higher than those of medium tasters and supertasters. PROP taster status did not have a significant multivariate effect on bitterness ratings of the three types of milk ($F[6, 182] = 1.02$; $p > 0.05$).

All three taster groups had a similar mean bitterness rating for broccoli and spinach. Supertasters had a slightly higher mean bitterness rating of Brussels sprouts and parsnips than non-tasters and medium tasters. Conversely, non-tasters had a marginally higher bitterness rating for carrots than medium tasters and supertasters. However PROP taster status did not have a significant multivariate effect on bitterness ratings of cruciferous and non-cruciferous vegetables ($F[10, 184] = 0.81$; $p > 0.05$).

Non-tasters had the highest mean bitterness rating for orange juice. Mean bitterness ratings for the three tasters groups were similar for unsweetened grapefruit juice, with supertasters' mean rating being marginally higher. Bitterness ratings of orange juice and grapefruit juice were not correlated ($r = 0.15$, $p > 0.05$). Therefore two separate ANOVAs were carried out. PROP taster status had no significant effect on bitterness ratings for orange juice ($F[2, 95] = 2.63$; $p > 0.025$) or grapefruit juice ($F[2, 95] = 1.31$; $p > 0.025$).

4.4.6 PROP Taster Status and Fattiness Ratings

TABLE 4.5
NON-TASTERS', MEDIUM TASTERS', AND SUPERTASTERS' MEAN FATTINESS RATINGS

	Mean (SD)		
	Non-tasters	Medium Tasters	Supertasters
Mild Cheddar	69 (12.7)	69 (18.0)	66 (22.4)
Mature Cheddar	64 (14.1)	64 (21.9)	61 (23.5)
Extra Mature Cheddar	58 (23.5)	55 (26.4)	53 (25.4)
Low Fat Cheddar	41 (21.0)	44 (26.6)	44 (27.1)
Whole Milk	66 (23.9)	72 (23.2)	70 (26.0)
Semi-skimmed	50 (28.9)	53 (23.8)	49 (24.0)
Skimmed	30 (28.1)	33 (25.1)	25 (26.2)

All three taster groups gave similar fattiness ratings to all four cheddar cheeses and the milks (Table 4.5).

Taster status did not have a significant multivariate effect on perceived fattiness of 1) cheeses that vary in strength and fat content ($F[8, 186] = 0.18$; $p > 0.05$), 2) the three types of milk with varying fat content ($F[6, 184] = 0.45$; $p > 0.05$).

4.4.7 Effect of Dietary Restraint on Food Likes/Dislikes

4.4.7.1 Actual Tasting of Foods

TABLE 4.6
MEAN HEDONIC RATINGS OF TASTED FOODS FOR RESTRAINED AND UNRESTRAINED EATERS

	Mean (SD)	
	Unrestrained Eaters (N = 68)	Restrained Eaters (N = 30)
Mild cheddar	62.7 (30.3)	67.6 (19.2)
Mature cheddar	57.4 (31.0)	65.8 (23.3)
Extra Mature Cheddar	46.5 (31.2)	45.9 (29.7)
Low Fat Cheddar	36.5 (28.2)	46.8 (28.9)
Whole milk	57.4 (29.9)	44.4 (32.0)
Semi-skimmed Milk	56.0 (30.6)	55.7 (28.8)
Skimmed Milk	40.4 (31.3)	44.3 (30.9)
Parsnip	43.8 (30.3)	52.9 (30.4)
Brussels sprouts	35.9 (29.4)	56.8 (30.4)
Spinach	32.3 (27.2)	48.5 (33.4)
Broccoli	52.1 (29.7)	65.7 (29.8)
Carrot	65.1 (28.8)	65.6 (30.5)
Orange juice	83.9 (16.1)	79.2 (22.3)
Unsweetened grapefruit juice	33.4 (33.9)	42.1 (37.5)

Restrained eaters gave higher hedonic ratings to mild, mature and low fat cheddar, skimmed milk, parsnips, Brussels sprouts, spinach, broccoli, and unsweetened grapefruit juice, and lower hedonic ratings to full fat milk than unrestrained eaters (Table 4.6).

MANOVA analysis revealed that dietary restraint had a significant multivariate effect on liking of the vegetables that were tasted ($F[5, 92] = 3.366$, $p < 0.05$). There were significant univariate ($F[1, 96] = 10.274$, $p < 0.01$) and multivariate ($F[1, 96] = 10.274$, $p < 0.05$) effects for Brussels sprouts. Univariate F values approached significance for spinach ($F[1, 96] = 6.393$, $p = 0.013$) and broccoli ($F[1, 96] = 4.320$, $p = 0.04$) and the stepdown F test approached significance for spinach ($F[1, 95] = 3.381$, $p = 0.069$).

There was no overall multivariate effect of restrained eating on liking of the cheeses ($F[4, 93] = 1.167$, $p > 0.05$), milks ($F[3, 93] = 1.693$, $p > 0.05$), or fruit juices ($F[2, 95]$

= 1.874, $p > 0.05$). However the univariate and stepdown F values approached significance for low fat cheese (both: $F[1, 96] = 2.775$, $p = 0.099$) and whole milk (both: $F[1, 95] = 3.665$, $p = 0.059$).

4.4.7.2 Food Preference Questionnaire

TABLE 4.7
MEAN HEDONIC RATINGS OF ITEMS IN THE FOOD PREFERENCE QUESTIONNAIRE (THAT HAD ALSO BEEN TASTED) FOR RESTRAINED AND UNRESTRAINED EATERS

	Mean (SD)	
	Unrestrained Eaters (N = 68)	Restrained Eaters (N = 30)
Mild cheddar	61 (30.8)	74 (21.8)
Mature cheddar	59 (31.6)	70 (26.2)
Extra Mature Cheddar	49 (34.1)	56 (31.5)
Low Fat Cheddar	52 (26.4)	72 (21.9)
Whole milk	46 (31.7)	30 (32.3)
Semi-skimmed Milk	67 (28.9)	61 (26.6)
Skimmed Milk	38 (29.9)	59 (34.8)
Parsnip	49 (30.4)	59 (30.6)
Brussels sprouts	31 (30.9)	55 (35.8)
Spinach	42 (30.3)	52 (35.7)
Broccoli	63 (28.6)	75 (28.8)
Carrot	67 (25.5)	70 (25.5)
Orange juice	82 (20.4)	80 (18.6)
Unsweetened grapefruit juice	37 (31.9)	43 (37.4)

Using the food preference questionnaire, restrained eaters gave higher hedonic ratings to all four cheeses, skimmed milk, all five vegetables, unsweetened grapefruit juice, and lower hedonic ratings to full fat milk than unrestrained eaters (Table 4.7).

MANOVA analyses revealed that dietary restraint had a significant multivariate effect on self-reported liking of the cheeses ($F[4, 70] = 3.025$, $p < 0.05$) and milks ($F[3, 89] = 5.173$, $p < 0.05$). Univariate and stepdown values were significant for low fat cheddar cheese (univariate: $F[1, 73] = 11.787$, $p < 0.0125$; stepdown: $F[1, 73] = 11.787$, $p < 0.05$) and skimmed milk (univariate: $F[1, 91] = 8.985$, $p < 0.016$; stepdown: $F[1, 91]$ =

8.985, $p < 0.05$). The stepdown value for full fat milk was significant ($F[1, 91] = 5.395$, $p < 0.05$) though the corresponding univariate value approximated significance at an alpha level of 0.016 ($F[1, 91] = 5.395$, $p = 0.02$).

Pillai's trace approached significance for hedonic ratings of the vegetables ($F[5, 78] = 2.105$, $p = 0.07$). Univariate and stepdown values were significant for Brussels sprouts (univariate: $F[1, 82] = 9.873$, $p < 0.01$; stepdown: $F[1, 82] = 9.873$, $p < 0.05$).

Dietary restraint did not have a significant multivariate effect on hedonic ratings of orange and grapefruit juice ($F[2, 95] = 0.465$, $p > 0.05$).

Taking a correlational approach, self-reported liking of several high fat foods decreased and liking of several low fat foods increased with increasing dietary restraint scores (Table 4.8).

When foods were tasted, higher restraint scores were associated with decreased liking of low fat cheddar ($r = -0.26$, $p < 0.05$) and mature cheddar cheese ($r = 0.20$, $p < 0.05$), and increased liking of Brussels sprouts ($r = 0.29$, $p < 0.01$), and spinach ($r = 0.26$, $p < 0.01$).

TABLE 4.8
PEARSON'S CORRELATION COEFFICIENTS BETWEEN DIETARY RESTRAINT SCORES AND RESPONSES TO FOOD PREFERENCE QUESTIONNAIRES

Item	Pearson's r
Brussels sprouts	0.29*
Cabbage	0.20*
Cauliflower	0.28*
Low fat cheddar	0.41**
Chips	-0.26**
Cottage cheese	0.34*
Crisps	-0.30*
Diet cola	0.27*
Donuts	-0.21*
Skimmed milk	0.29*
Onions	0.28*
Flavoured soya milk	0.37*
Spinach	0.22*
Sunday roast	-0.23*

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed

4.4.8 The Effect of Dietary Restraint on the Relationship between PROP Tasting Ability and Food Likes/Dislikes

To determine whether dietary restraint could have negated a potential PROP effect on food likes/dislikes, the effect of PROP taster status on unrestrained eater's (N = 68; 10 NTs, 37 MTs, 21 STs) and restrained eater's (N = 30; 5 NTs, 14 MTs, 11 STs) food likes/dislikes was examined separately. The small proportion of restrained eaters results in small cell sizes so results for restrained eaters should be interpreted with caution.

4.4.8.1 Actual Tasting

For restrained eaters, supertasters gave the highest hedonic ratings to semi-skimmed and skimmed milks, all of the vegetables, and the lowest hedonic ratings to whole milk (Table 4.9). These patterns were not seen among the unrestrained eaters (Table 4.10).

TABLE 4.9
MEAN HEDONIC RATINGS OF TASTED FOODS FOR RESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 5)	Medium Tasters (N = 14)	Supertasters (N = 11)
Mild cheddar	60.7 (8.17)	68.4 (18.3)	69.8 (24.1)
Mature cheddar	79.6 (16.7)	58.3 (25.2)	69.0 (21.2)
Extra Mature Cheddar	58.9 (27.5)	36.6 (30.1)	51.6 (28.9)
Low Fat Cheddar	40.0 (19.6)	50.3 (29.1)	45.5 (33.6)
Whole milk	55.2 (34.1)	42.7 (31.6)	41.6 (33.7)
Semi-skimmed Milk	44.6 (31.6)	46.4 (27.9)	71.7 (23.1)
Skimmed Milk	43.4 (19.0)	34.5 (32.8)	56.3 (30.8)
Parsnip	38.5 (31.6)	52.5 (30.4)	60.0 (37.1)
Brussels sprouts	46.2 (33.6)	51.6 (29.9)	68.3 (28.8)
Spinach	29.6 (24.3)	45.9 (31.8)	60.5 (36.5)
Broccoli	38.3 (16.4)	65.9 (29.5)	77.8 (28.3)
Carrot	53.8 (19.2)	61.5 (33.9)	76.2 (28.9)
Orange juice	76.7 (19.9)	80.5 (23.8)	78.7 (23.4)
Unsweetened grapefruit juice	27.4 (27.1)	46.5 (40.9)	43.1 (38.5)

TABLE 4.10
MEAN HEDONIC RATINGS OF TASTED FOODS FOR UNRESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 10)	Medium Tasters (N = 37)	Supertasters (N = 21)
Mild cheddar	68.6 (31.1)	61.8 (31.7)	61.4 (28.6)
Mature cheddar	53.0 (34.3)	55.1 (31.0)	63.6 (30.0)
Extra Mature Cheddar	42.3 (32.9)	45.5 (32.4)	50.3 (29.4)
Low Fat Cheddar	31.2 (29.7)	33.4 (27.5)	44.4 (28.2)
Whole milk	59.9 (30.6)	59.0 (29.9)	53.5 (30.7)
Semi-skimmed Milk	50.5 (30.5)	57.9 (31.3)	55.4 (30.5)
Skimmed Milk	33.9 (37.4)	45.0 (29.5)	35.2 (31.6)
Parsnip	36.0 (29.5)	43.6 (31.2)	47.8 (29.8)
Brussels sprouts	32.9 (18.6)	41.1 (31.8)	28.3 (28.4)
Spinach	10.7 (5.9)	37.1 (28.7)	34.3 (26.6)
Broccoli	47.8 (24.8)	53.4 (31.6)	51.8 (29.6)
Carrot	70.0 (17.8)	64.3 (32.3)	64.0 (27.3)
Orange juice	90.0 (7.0)	84.6 (11.6)	79.8 (23.9)
Unsweetened grapefruit juice	32.2 (28.6)	37.4 (35.5)	27.0 (33.5)

For the unrestrained eaters, there was no multivariate effect of PROP taster status on hedonic ratings of: 1) the four cheeses ($F[8, 126] = 0.718$, $p > 0.05$); 2) the milks ($F[6, 128] = 0.480$, $p > 0.05$), 3) the vegetables ($F[10, 124] = 1.423$, $p > 0.05$), or 4) grapefruit and orange juices ($F[4, 130] = 0.955$, $p > 0.05$). The stepdown F test for spinach showed a significant PROP effect for hedonic ratings of spinach ($F[2, 65] = 4.120$, $p < 0.05$), although the univariate F test only approached significance at an alpha level of 0.01 ($F[2, 65] = 4.120$, $p = 0.021$). Non-tasters' mean hedonic rating of spinach was lower than those of medium tasters and supertasters' (NTs = 11 ± 5.9; MTs = 37 ± 28.7; STs = 34 ± 26.6).

For the restrained eaters, there was also no multivariate PROP effect for hedonic ratings of the: 1) cheeses ($F[8, 50] = 1.220$, $p > 0.05$), 2) milks ($F[6, 50] = 1.474$, $p > 0.05$); 3) vegetables ($F[10, 48] = 1.139$, $p > 0.05$); or 4) fruit juices ($F[4, 54] = 0.235$, $p > 0.05$). However, the univariate and stepdown F statistics came close to significance for hedonic ratings of semi-skimmed milk (both: $F[2, 26] = 3.169$, $p = 0.059$). Supertasters gave a higher mean hedonic rating to semi-skimmed milk than non-tasters and medium tasters (NTs = 45 ± 31.6; MTs = 46 ± 27.9; STs = 72 ± 23.1).

4.4.8.2 Food Preference Questionnaires

TABLE 4.11
MEAN HEDONIC RATINGS OF ITEMS IN THE FOOD PREFERENCE QUESTIONNAIRE (THAT HAD ALSO BEEN TASTED) FOR RESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 5)	Medium Tasters (N = 14)	Supertasters (N = 11)
Mild cheddar	67 (17.6)	76 (18.7)	71 (25.9)
Mature cheddar	69 (8.2)	70 (26.6)	67 (30.4)
Extra Mature Cheddar	60 (20.9)	57 (35.2)	50 (31.2)
Low Fat Cheddar	57 (12.5)	75 (17.9)	71 (28.9)
Whole milk	47 (39.8)	10 (12.8)	45 (34.2)
Semi-skimmed Milk	56 (21.9)	56 (31.7)	73 (19.9)
Skimmed Milk	47 (34.2)	66 (34.9)	59 (36.7)
Parsnip	41 (36.8)	60 (32.9)	67 (28.5)
Brussels sprouts	44 (39.3)	46 (37.7)	66 (32.5)
Spinach	52 (30.2)	50 (40.9)	57 (32.9)
Broccoli	42 (27.4)	79 (26.4)	80 (24.9)
Carrot	56 (24.6)	68 (30.4)	66 (28.9)
Orange juice	76 (23.0)	78 (20.8)	86 (13.6)
Unsweetened grapefruit juice	54 (36.6)	46 (39.5)	32 (35.7)

Among the restrained eaters, supertasters gave the highest mean hedonic ratings to semi-skimmed milk, parsnips, Brussels sprouts, spinach, broccoli and orange juice, and the lowest mean hedonic rating to extra mature cheddar and unsweetened grapefruit juice (Table 4.11).

Among the unrestrained eaters, non-tasters gave the highest mean hedonic ratings to mild and mature cheddar cheese, all three milks, Brussels sprouts, broccoli, carrot, orange juice, and grapefruit juice, and the lowest mean hedonic rating to low fat cheddar cheese and spinach (Table 4.12).

For the unrestrained eaters, there was no multivariate effect of PROP taster status on hedonic ratings of: 1) the four cheeses ($F[8, 86] = 0.894$, $p > 0.05$), 2) the milks ($F[6, 120] = 0.526$, $p > 0.05$), 3) the vegetables ($F[10, 104] = 0.829$, $p > 0.05$), or 4) grapefruit and orange juices ($F[4, 130] = 0.341$, $p > 0.05$).

TABLE 4.12
MEAN HEDONIC RATINGS OF ITEMS IN THE FOOD PREFERENCE QUESTIONNAIRE (THAT HAD ALSO BEEN TASTED) FOR UNRESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 10)	Medium Tasters (N = 37)	Supertasters (N = 21)
Mild cheddar	72 (29.1)	59 (32.1)	63 (27.0)
Mature cheddar	73 (30.4)	55 (32.2)	57 (32.0)
Extra Mature Cheddar	45 (34.6)	45 (34.2)	48 (37.8)
Low Fat Cheddar	44 (35.7)	53 (27.5)	52 (21.0)
Whole milk	50 (32.2)	47 (29.5)	46 (34.9)
Semi-skimmed Milk	74 (27.3)	68 (28.0)	59 (28.9)
Skimmed Milk	48 (32.8)	37 (29.4)	35 (30.0)
Parsnip	45 (24.2)	50 (31.5)	45 (31.4)
Brussels sprouts	38 (26.7)	34 (32.4)	25 (31.2)
Spinach	30 (31.8)	47 (31.1)	37 (24.7)
Broccoli	69 (21.0)	57 (32.1)	61 (28.4)
Carrot	72 (20.7)	61 (30.0)	65 (24.0)
Orange juice	84 (16.5)	83 (20.6)	79 (22.3)
Unsweetened grapefruit juice	43 (22.0)	39 (31.9)	32 (36.2)

For the restrained eaters, there was also no multivariate PROP effect on hedonic ratings of the: 1) cheeses (F[8, 44] = 0.905, $p > 0.05$), 2) milks (F[6, 50] = 2.190, $p > 0.05$); 3) vegetables (F[10, 40] = 1.073, $p > 0.05$); or 4) fruit juices (F[4, 54] = 1.507, $p > 0.05$). Pillai's trace for the milks approximated significance ($p = 0.59$), and both the univariate (F[2, 26] = 1.963, $p < 0.017$) and stepdown (F[2, 26] = 1.963, $p < 0.05$) statistics for full fat milk were statistically significant.

Unrestrained eaters liking of the combined high fat food items ($r = 0.33, p < 0.05$), dark chocolate ($r = 0.26$, $p < 0.05$), lager ($r = 0.27$, $p < 0.05$), horseradish ($r = 0.44$, $p < 0.05$), and tofu ($r = 0.43$, $p < 0.05$), increased with increasing PROP thresholds (i.e. decreasing PROP sensitivity). When hedonic ratings were correlated with PROP/NaCl ratios, unrestrained eaters liking of margarine ($r = -0.26, p < 0.05$) and runner beans ($r = -0.26$, $p < 0.05$) decreased with increasing PROP/NaCl ratios (i.e. increasing PROP acuity).

Among the restrained eaters, low PROP thresholds were associated with increased liking of alcopops ($r = 0.55$, $p < 0.05$) and decreased liking of broccoli ($r = -0.38$, $p < 0.05$) and onions ($r = -0.46$, $p < 0.05$). Looking at PROP/NaCl ratios, restrained eaters' hedonic ratings of chips ($r = -0.40$, $p < 0.05$) and fish and chips ($r = -0.49$, $p < 0.05$) decreased with increasing PROP acuity, and hedonic ratings of broad beans ($r = 0.39$, $p < 0.05$), gin ($r = 0.49$, $p < 0.05$), horseradish ($r = 0.38$, $p < 0.05$), and lemon juice ($r = 0.37$, $p < 0.05$) increased.

4.4.9 Effect of Dietary Restraint on Fattiness Ratings and PROP Tasting Ability

TABLE 4.13
MEAN FATTINESS RATINGS OF TASTED FOODS FOR RESTRAINED AND UNRESTRAINED EATERS

	Mean (SD)	
	Unrestrained Eaters (N = 68)	Restrained Eaters (N = 30)
Mild cheddar	66.7 (20.5)	70.4 (14.0)
Mature cheddar	62.9 (21.0)	62.3 (22.6)
Extra Mature Cheddar	56.4 (25.0)	51.9 (26.7)
Low Fat Cheddar	45.2 (25.9)	39.4 (25.5)
Whole milk	69.2 (24.0)	72.8 (24.4)
Semi-skimmed Milk	50.4 (23.3)	52.6 (27.4)
Skimmed Milk	28.7 (27.0)	31.5 (23.5)

Restrained and unrestrained eaters gave similar mean fattiness ratings to the cheeses and milks that were tasted (Table 4.13). Multivariate analysis of variance confirmed this (cheeses: $F[4, 93] = 0.648$, $p > 0.05$; milks: $F[3, 92] = 0.267$, $p > 0.05$).

Restrained supertasters gave marginally higher fattiness ratings to mild and mature cheddar cheeses. They also gave the highest fattiness ratings to whole milk and the lowest fattiness ratings to skimmed milk (Table 4.14). Converse patterns were found among the unrestrained eaters (Table 4.15). The supertasters had the lowest fattiness ratings mild and mature cheddar cheeses and whole milk.

TABLE 4.14
MEAN FATTINESS RATINGS OF TASTED FOODS FOR RESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 5)	Medium Tasters (N = 14)	Supertasters (N = 11)
Mild cheddar	65.2 (14.3)	69.6 (12.9)	73.9 (15.5)
Mature cheddar	64.7 (22.3)	56.8 (24.4)	68.1 (20.6)
Extra Mature Cheddar	64.7 (23.1)	46.6 (27.5)	52.8 (27.3)
Low Fat Cheddar	52.5 (26.9)	33.2 (20.8)	41.3 (29.9)
Whole milk	58.6 (21.9)	70.3 (26.1)	82.4 (21.1)
Semi-skimmed Milk	46.5 (23.4)	58.2 (27.6)	48.7 (29.9)
Skimmed Milk	34.4 (20.0)	44.2 (25.4)	15.3 (10.3)

TABLE 4.15
MEAN FATTINESS RATINGS OF TASTED FOODS FOR UNRESTRAINED NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

Tasted Food	Mean (SD)		
	Non-tasters (N = 10)	Medium Tasters (N = 37)	Supertasters (N = 21)
Mild cheddar	71.0 (12.2)	68.1 (19.7)	62.1 (24.7)
Mature cheddar	63.2 (9.4)	66.1 (20.7)	57.1 (24.6)
Extra Mature Cheddar	54.5 (24.2)	58.3 (25.6)	53.8 (25.1)
Low Fat Cheddar	34.5 (15.7)	48.3 (27.6)	44.7 (26.2)
Whole milk	70.0 (25.1)	72.7 (22.5)	62.9 (26.2)
Semi-skimmed Milk	52.2 (32.3)	50.5 (22.3)	49.3 (21.2)
Skimmed Milk	27.7 (32.1)	28.4 (24.0)	29.8 (30.5)

There was no PROP effect on unrestrained eaters' fattiness ratings of the cheeses ($F[8, 126] = 0.742, p > 0.05$) and milks ($F[6, 126] = 0.378, p > 0.05$) (Table 4.11).

Among the restrained eaters, the three taster groups' fattiness ratings of the cheeses were also not significantly different ($F[8, 50] = 0.616, p > 0.05$). However there was a significant multivariate effect for the milks ($F[6, 50] = 2.357, p < 0.05$). The univariate and stepdown F statistics were significant for fattiness ratings of skimmed milk (both: $F[2, 26] = 6.302, p < 0.05$). Supertasters gave the lowest fattiness ratings (NTs = 34, SD = 20.0; MTs = 44, SD = 25.4; STs = 15, SD = 10.3; Table 4.10). Supertasters heightened discriminating ability may have led them to correctly identify the low fat content in skimmed milk.

There were no significant associations between restraint scores and fattiness ratings (r = 0.043 to 0.19).

4.4.10 Taste Likes, Self-reported Liking, and Self-reported Food Frequency

TABLE 4.16
CORRELATIONS BETWEEN TASTE LIKES, SELF-REPORTED FOOD LIKES, AND SELF-REPORTED FREQUENCY OF CONSUMPTION

Food	N	Taste likes and self-reported likes (Pearson)	Taste likes and self-reported frequency of consumption - FFQ (Tau) †	Self-reported food likes and self-reported frequency of consumption (Tau) †
Mild cheddar	97	0.43**	0.23**	0.39**
Mature cheddar	97	0.45**	N/A	N/A
Extra mature cheddar	94	0.39**	N/A	N/A
Low fat cheddar	77	0.39**	N/A	N/A
Whole milk	95	0.52**	N/A	N/A
Semi-skimmed milk	96	0.36**	N/A	N/A
Skimmed milk	93	0.44**	N/A	N/A
Parsnip	90	0.69**	0.41**	0.47**
Brussels sprouts	98	0.79**	0.45**	0.57**
Spinach	89	0.53**	0.19*	0.42**
Broccoli	98	0.67**	0.35**	0.48**
Carrot	98	0.73**	0.24**	0.38**
Orange Juice	98	0.53**	N/A	N/A
Grapefruit juice	98	0.73**	0.47**	0.48**

* $p < 0.05$, two tailed
** $p < 0.01$, two tailed
† Some of the food items that were tasted were not included in the food preference questionnaire and/or the food frequency questionnaire.

Correlations between hedonic ratings based on tasting and self-reported hedonic ratings in the food preference questionnaire ranged from 0.36 to 0.79 and were all significant (Table 4.16). The correlations between self-reported intake (FFQ) and taste likes and self-reported likes were noticeably lower. Self-reported food likes/dislikes were more highly correlated with self-reported food frequencies than taste likes/dislikes.

4.4.11 PROP Taster Status and BMI/Dietary Restraint

BMI data was missing for one medium taster. BMI was inversely related to PROP sensitivity (NTs>MTs>STs; Table 4.17), but this difference was not significant ($F[2, 94] = 0.48$, $p > 0.05$). Nontasters had a mean BMI less than one point higher than that of medium tasters, who in turn were half a BMI point heavier than supertasters. The mean BMI of the whole sample was 23.3 which falls in the acceptable weight range (20 - 25).

TABLE 4.17
MEAN BODY MASS INDEX ACCORDING TO PROP TASTER STATUS

PROP Taster Status	N	Mean BMI (SD)
Non-tasters	15	24.2 (6.1)
Medium Tasters	50	23.4 (4.0)
Supertasters	32	22.9 (3.3)
Total	97	23.3 (4.1)

PROP taster status had no association with dietary restraint scores ($F[2, 95] = 0.17$; $p > 0.05$). However, dietary restraint did significantly affect BMI, with restrained eaters having a higher BMI than unrestrained eaters ($t = -3.43$, $df = 44.87$; $p < 0.05$). Restrained eaters had a mean BMI of 25.6 (SD: 4.57) and unrestrained eaters a mean BMI of 22.3 (SD: 3.50).

Although non-tasters had a higher mean BMI than supertasters for both restrained and unrestrained eaters (Table 4.18), neither was significant (unrestrained eaters: $F[2, 64] = 0.82$, $p > 0.05$; restrained eaters: $F[2, 27] = 0.08$, $p > 0.05$).

TABLE 4.18
MEAN BODY MASS INDEX ACCORDING TO PROP TASTER STATUS FOR RESTRAINED AND UNRESTRAINED EATERS

PROP Taster Status		Mean (SD)	
		Unrestrained eaters (N = 67)	Restrained eaters (N = 30)
Non-tasters	(N = 15)	23.4 (7.1)	25.6 (3.5)
Medium Tasters	(N = 50)	22.4 (2.6)	25.9 (5.6)
Supertasters	(N = 32)	21.7 (2.2)	25.1 (3.8)
Total	(N = 97)	22.3 (3.5)	25.6 (4.6)

4.4.12 Smoking

There were 34 smokers and 63 non-smokers in the sample (one participant who had very recently given up smoking could not be classified). A higher percentage of non-tasters were smokers compared to medium tasters and supertasters (Table 4.19). 47% of non-tasters were smokers, compared to 35% of medium tasters and 29% of supertasters. However this difference was not significant ($\chi^2 = 1.38$; $df = 2$; $p > 0.05$).

PROP taster status also had no significant effect on number of cigarettes smoked per day ($H = 0.64$: $df = 2$; $p > 0.05$; Table 4.20).

Smoking and non-smoking had no significant association with PROP thresholds (U = 1056.00, $p > 0.05$) or their PROP/NaCl ratios (U = 924.50, $p > 0.05$; Table 4.21).

TABLE 4.19
FREQUENCY OF SMOKERS AND NON-SMOKERS

	Smokers (%)	Non-smokers (%)
Non-tasters	7 (46.7%)	8 (53.3%)
Medium Tasters	8 (35.3%)	33 (64.7%)
Supertasters	9 (29.0%)	22 (71.0%)

TABLE 4.20
PROP TASTER STATUS AND MEDIAN SELF-REPORTED NUMBER OF CIGARETTES SMOKED PER DAY

	Median Number of cigarettes (IQR)
Non-tasters	10 (9.0)
Medium Tasters	10 (14.3)
Supertasters	10 (5.8)

TABLE 4.21
MEDIAN PROP THRESHOLD AND PROP/NACL RATIO FOR SMOKERS AND NON-SMOKERS

	Median (IQR)	
	Smokers	Non-smokers
Median PROP Threshold	5.9 (4.3)	6.3 (4.0)
Median PROP/NaCl Ratio	0.7 (0.9)	0.8 (1.0)

4.4.13 Extraneous Factors

Head injury, ear infection, x-rays, colds, and wearing a dental plate could potentially affect PROP tasting ability and ultimately its relationship with food choice. No participants wore a dental plate and only one had had an x-ray in the previous two weeks. There were no significant differences between thresholds or PROP/NaCl ratios ($t = 1.39$, $df = 13$, $p > 0.05$) for those with or without: head injury (thresholds: $t = -0.65$, $df = 96$, $p > 0.05$; ratios: $t = 1.39$, $df = 13$, $p > 0.05$); ear infections (thresholds: $t = 0.45$, $df = 96$, $p > 0.05$; ratios: $t = 0.95$, $df = 96$, $p > 0.05$); a cold (thresholds: $t = 1.75$, $df = 95$, $p > 0.05$; ratios: $t = -0.57$, $df = 95$, $p > 0.05$) (Table 4.22).

TABLE 4.22
MEAN PROP THRESHOLDS AND PROP/NACL RATIOS ACCORDING TO PRESENCE/ABSENCE OF HEAD INJURIES, EAR INFECTIONS, AND COLDS

Pathology	N		Mean (SD)	
			PROP Threshold	PROP/NaCl Ratio
Head Injuries	Yes	14	5.9 (2.1)	4.8 (9.4)
	No	84	6.4 (2.8)	1.3 (1.6)
Ear Infections	Yes	46	6.4 (2.7)	2.2 (5.4)
	No	52	6.2 (2.8)	1.4 (2.0)
Colds	Yes	23	7.1 (2.4)	1.4 (1.7)
	No	74	6.0 (2.8)	1.9 (4.4)

4.4.14 Relationship between PROP Tasting and Age

There was no significant association between PROP threshold scores and age ($r = -0.09$, $p > 0.05$). However there was a significant correlation between PROP/NaCl ratios and age ($r = 0.31$, $p < 0.05$), indicating that PROP taste acuity increased with age.

4.5 Discussion

4.5.1 PROP Acuity and Food Likes/Dislikes

There was no significant relationship between PROP taster status and actual or reported food likes/dislikes. There were very few small, but significant, correlations between PROP acuity and items in the food preference questionnaire, which is weak evidence for a PROP effect. Findings in the relevant literature are inconsistent. Most studies that found a significant effect of PROP taster status on food likes/dislikes reported an association for some foods (often for only a small proportion of those tested) but not for others with no consistent trend for type of food (e.g. Drewnowski, Henderson and Shore, 1997b; Jefferson and Erdman 1970). Other studies found no effect (Niewind, Krondl, and Shrott, 1988) or an effect in another direction (Tuorila et al., 1997; Bauer and Utermohlen, 1999).

Recent studies have examined factors that might influence the relationship between PROP tasting ability and food likes/dislikes, factors which may have contributed to the inconsistency of findings in the literature. PROP perception has been found to influence food likes/dislikes by interacting with age and sex (Snyder et al., 2001). Older non-taster women liked sweet foods the least whereas middle-aged male supertasters liked high-fat foods the most. Ullrich and Tepper (2001) found that only tasters with low food adventurousness scores (low willingness to try new foods) showed the characteristic rejection of strong tasting foods. Tasters with high food adventurousness scores had higher hedonic ratings than tasters with low adventurousness scores. Willingness to try new foods had no effect on non-tasters scores. This suggests the possibility that the taster groups showed differences in attitudes rather than "taste" responsiveness.

The foods in the food preference questionnaire were not eaten very often. Although the vast majority of items are very common, few foods were eaten on a daily basis and many foods were eaten only rarely. This reduced the data available for each participant, and perhaps contributed to the lack of associations in the checklist.

Other factors involved in food likes/dislikes could negate the potential impact of PROP acuity. Rozin and Vollmecke (1986) in an influential review paper asserted that besides availability and economic factors, all other influences of food likes/dislikes can be categorised as biological (genetically determined), cultural, or psychological factors, and that food likes/dislikes are influenced by an interaction between them. However, the extent to which each of these factors influence food likes and the nature of the interactions between them remains largely unknown (Frank et al., 1995). Awareness of the multiple aetiology of food choice prompted the examination of the effect of dietary restraint on likes/dislikes, to explore whether it could negate a potential PROP effect.

4.5.2 Effect of Dietary Restraint on Food Likes/Dislikes

For the foods that were tasted, restrained eaters reported liking the vegetables significantly more than the unrestrained eaters. Restrained eaters also tended to like the low fat cheddar more than the unrestrained eaters, and liked whole milk less. For the food preference questionnaire, restrained eaters liked the cheeses significantly more than the unrestrained eaters, with the biggest difference for low fat cheese. There was also a significant difference between restrained and unrestrained eaters hedonic ratings of the milks with restrained eaters liking the skimmed milk more, and full fat and semi-skimmed milk less, than the unrestrained eaters. Although the same trends were seen for both measures of likes/dislikes, these results show how actual tasting and use of a FPQ identify significant findings for different types of foods.

Results of similar studies in the literature are mixed. French et al. (1994) found no effect of dieting status (based on the restraint component of the Three Factor Eating Questionnaire, as also used in the present study) on food likes/dislikes in both men and women. However Sunday et al. (1992) reported that chronic dieters (also identified using the TFEQ-R) liked several types of high fat foods (e.g. high-fat dairy products and oils) less than non-dieters. Similarly, Contento et al. (1995) found that adolescents who never dieted (not based on a restraint measure) valued tastiness of foods more as a food choice criterion than those who dieted often, though both groups rated taste as an important factor. However, taste was equally important for actual food choice.

4.5.3 The Effect of Dietary Restraint on the Relationship between PROP Tasting Ability and Food Likes/Dislikes

The fact that there was no effect of PROP taster status on food likes/dislikes, but that dietary restraint did have significant effects on hedonic ratings, suggests that dietary restraint could obscure potential PROP effects.

Among both restrained and unrestrained eaters, PROP taster status had no effect on food likes/dislikes of the foods that were tasted. Duffy, Weingarten and Bartoshuk (1995) found that tasters' increased liking of foods high in fat and sweet were no longer significant when the restrained eaters were removed.

4.5.4 PROP Taster Status and Bitterness Ratings and Fattiness Ratings

PROP taster status did not affect bitterness and fattiness ratings of the tasted foods. Several other studies also did not find a relationship between taster status and bitterness of vegetables (Mattes and Labov, 1989; Jerzsa-Latta, Krondl, and Coleman, 1990; Niewind, Krondl, and Shrott, 1988) although the former two studies measured responses to questionnaires rather than actual tasting. Marino et al. (1991) found that although there was a PROP effect for single bitter taste components in cheese (i.e. calcium chloride and casein), tasters rated only two of eight cheeses as more bitter. Tasters' and non-tasters' creaminess ratings did not differ. Duffy et al. (1996) examined creaminess ratings of milk products with varying fat contents ranging from less than 0.5% to 54%. Creaminess ratings of products containing 11.5%, 36%, and 54% fat were significantly higher among supertasters than medium tasters or non-tasters, with no PROP effects for those with the lowest fat contents (<0.5, 1, 2, and 3.5%). The percentages of fat in the milks used in the present study correspond to these lower preparations; the whole milk contained less than 4% fat. Tuorila et al. (1997) found that individuals with greater PROP acuity gave higher bitterness ratings to low fat cream cheese samples (10% fat), but the lowest ratings to high fat samples (40% fat). They suggested that the latter finding could be attributed to a suppressing effect of fat on perceived taste intensity in tasters compared to non-tasters. There is also some evidence for a masking effect in the current data. The sample gave the lower fattiness ratings to the stronger cheeses than the mild cheddar cheese (mild > mature > extra mature). Other studies have found that supertasters have a heightened perception of fat in salad dressings, guar gum and corn oil which are less complex (Tepper and Nurse, 1997a; Tepper and Nurse, 1997b; Prutkin, unpublished thesis, cited in Prutkin et al., 2000; Prutkin et al., 1999a). Untrained participants are able to accurately judge the fat content of stimuli when assessing model and simple food systems with few components, but find it more difficult when more complex, semi-solid or solid stimuli are tasted (Yackinous and Guinard (2001).

4.5.5 Taste Likes/Dislikes, Self-reported Likes/Dislikes, and Self-reported Food Intake

Food likes/dislikes based on tasting and self-reported food likes/dislikes in the food preference questionnaire were related as previously reported (Kaminski et al., 2000; Ly and Drewnowski, 2001). Small to moderate associations also existed between food liking (both measures) and frequencies of food intake. Drewnowski and Hann (1999) also observed that self-reported food likes/dislikes and food frequencies were significantly associated. Self-reported food frequencies were more highly correlated with self-reported food likes/dislikes than with food likes/dislikes based on tasting of food items (also found by Kaminski et al., 2000). This could be more to do with similarity of task/required responding to questionnaires than the possibility that food preference questionnaires are a better measure of food likes/dislikes than use of actual tasting, or better predictors of (self-reported) food intake.

4.5.6 The Effect of PROP Taster status on Body Mass Index and Smoking

As found and discussed in Chapter Three, there were non-significant tendencies for individuals with greater PROP acuity to have a lower BMI and be less likely to smoke. Forty participants in the current study had previously taken part in the food intake study which would have contributed, at least in part, to the consistency of findings.

4.5.7 Summary/Conclusion

PROP taster status did not affect liking of, or perceived bitterness and fattiness of, real complex foods. There were also no PROP effects when liking was measured using responses to questionnaire items. However there were significant effects of dietary restraint on food likes/dislikes, using both measures of liking. Restrained supertasters tended to give higher hedonic ratings to the reduced fat milks and the vegetables and lower ratings to full fat milk than non-tasters and medium tasters, trends not seen among the unrestrained eaters. It is possible that restrained supertasters conscious efforts to control their food intake may override their taste likes or dislikes.

Chapter Five

Taste Acuity for 6-N-Propylthiouracil (PROP): A Possible Genetic Marker for Coronary Heart Disease?

5.1 Abstract

To explore whether genetically mediated taste acuity for PROP functions as a genetic taste marker for diet-related disease, PROP intensity ratings of participants with coronary heart disease (CHD) were compared with ratings of those without CHD. Two hundred and nineteen participants (162 males; 57 females; 44 - 88 years; mean age: 65.9, SD: 7.3 years) completed questionnaires either at coronary support groups or via post in response to poster advertisements or requests to pensioner action groups. Ratings of PROP paper were made on a 100 mm General Labelled Magnitude Scale (gLMS). Demographic information and data on food likes/dislikes and smoking and drinking habits were also obtained. Men with CHD had a lower taste acuity for PROP compared with men without CHD, and women with CHD showed *greater* PROP acuity than women without CHD. This suggests that heightened PROP tasting ability is protective in men and decreased acuity may be protective in women. However the results for women need to be interpreted with caution given the small sample size. This exploratory study warrants further population studies of coronary heart disease and potentially other diet-related diseases. Further support for the present findings would have implications for the use of PROP testing as a screening tool to identify individuals at increased disease risk, and for health programmes that promote dietary change which often overlook taste as a barrier to adopting healthy eating habits.

5.2 Introduction

In 1994 the Committee on Medical Aspects of Food and Nutrition Policy (COMA), an advisory body to the UK government, reviewed the links between diet and heart disease. It concluded that diet is a major and modifiable cause of cardiovascular disease, and can therefore be considered central to prevention (DoH, 1994). Coronary heart disease (CHD) is a form of cardiovascular disease which manifests as angina, acute myocardial infarction ("heart attack"), or sudden death, with or without a history of previous infarction and/or preceding chest pain (DoH, 1994). It is the leading cause of death in England, accounting for 21% of deaths (ONS, 1999).

Modifications to diet to decrease the risk of developing CHD, or indeed to help an existing condition, involve reducing sodium intake, decreasing intake of fat, especially saturated fat and trans fatty acids, and compensating for this energy deficit with increased consumption of complex carbohydrates and fruit and vegetables (DoH, 1994, 1992, 1998; Hughes, unpublished, cited in DoH, 2000b). These dietary changes can reduce blood pressure and cholesterol levels and increase levels of beneficial compounds such as antioxidants in the blood (Hughes, 2000).

Strategies employed by the UK government to encourage dietary change primarily involve nutrition education. However, whilst there is a good level of awareness about what constitutes a healthy diet in the population, this has not translated into marked behavioural change (Mathers, 2000). The government is currently developing a "five-a-day" programme using mere exposure as the primary strategy. Its aim is to encourage the target of eating five portions of fruit and vegetables per day as part of the government's commitment to preventing disease and reducing health inequalities (DoH, 2000a). The National School Fruit Scheme (DoH, 2000b), which is currently in its pilot stage and will be fully operational in 2004, provides four to six-year-olds with a free piece of fruit each school day. Suggested effective strategies include tasting sessions to promote mere exposure, role modelling by including older children in fruit only tuck shops, reward schemes, and nutritional education. Five-a-day pilot initiatives have also been set up in five deprived areas of England, which will inform a roll-out across the country from 2002. It will also primarily involve exposure and increased availability as well as social and psychological factors through tasting and cooking sessions, community cafes and breakfast clubs, community allotments and association with the local football team.

The role of sensory factors as a taste barrier to adopting healthy dietary habits has been overlooked by national programmes promoting dietary change in both Britain and America (Drewnowski, Kristal, and Cohen, 2001; Drewnowski and Gomez-Carneros, 2000). In particular, genetically mediated taste acuity for 6-n-propylthiouracil (PROP) has been associated with enhanced responsiveness to some foods, and therefore possibly patterns of food acceptance and food rejection that are considered to be (un)healthy (Drewnowski and Rock, 1995; Tepper, 1998; Drewnowski, Henderson, and Barratt-Fornell, 2001). Bitter-tasting cruciferous vegetables are excellent sources of cancer-preventative agents such as phytochemicals (Drewnowski and Rock, 1995) and isothiocyanates (Stoner et al., 1991). Supertasters' heightened perception of their bitter taste may lead to the rejection of these foods and thus increased risk of cancer. Excessive consumption of fats and sugars are also reported to contribute to cancer as well as other diet-related diseases such as obesity, hypertension, and cardiovascular disease (Drewnowski, 1990b). Non-tasters' decreased perception of fats means that they need higher levels of those fats to perceive their sensory qualities which may lead them to consume high levels of fat in their diet. On the other hand, non-tasters may more easily adjust to switching to low-fat alternatives of certain foods (e.g. from whole milk to semi-skimmed) than supertasters as they are less able to detect the difference in fat content and taste, which may be advantageous to their health. Dietary intervention programmes may be more effective if they recognised the role of taste barriers (Lloyd et al., 1995). It may be necessary to develop methods of making rejected health promoting foods more palatable.

There has been little study of the possible link between genetically mediated taste acuity for PROP and the development of diet-related disease. The few existing studies tended to focus on cancers.

Milunicová et al. (1969) examined the incidence of tasting/non-tasting ability in groups of individuals with cancers of various organs, as well as in patients with non-cancerous disease of the same organs. PTC taster status in these groups was compared with taster status in healthy males and females. Compared to healthy females, there were significantly lower rates of non-tasting among groups with malignant tumours in the uterus, cervix, ovaries, vulva, breasts, and the thyroid gland. In contrast, the frequency of non-tasters among healthy same-sex controls was not statistically different to rates among: males with thyroid cancer; both males and females with cancer of the digestive tract; males with lung cancer (females with lung cancer not studied); groups with non-malignant disorders including endometrial disorders, prostate disorders and males with pulmonary tuberculosis. This suggests that female non-tasters are less susceptible to malignant tumours of the thyroid gland, breasts, uterus, cervix and ovaries than tasters. Or, cancer could possibly cause changes in PROP acuity. Since such trends for other cancers were not observed among men, Milunicová et al. suggested that the possible protective function of non-tasting is conditional upon the presence of female hormones. In support of this hypothesis, 15%, 20%, and 25% of the women who had thyroid, breast, and genital cancer respectively were over 60 years old, thus with decreased levels of female hormones, compared with 50% of women with cancer of the digestive tract who showed similar proportions of non-tasting as healthy women. Perhaps the higher proportion of older adults and thus an age-related decline in PTC sensitivity may also be involved the failure to find a reduced frequency of non-tasters in women with cancer of the digestive tract.

Ahuja et al.'s (1977) finding that there was a significantly *higher* frequency of non-tasters among patients with cervical cancer (59%), compared to healthy controls (30%), conflicts with Milunicová et al.'s report of a decreased incidence of non-tasters. Their statement that carcinoma of the cervix tends to be higher in women undergoing oestrogen therapy or having high oestrogen levels due to other reasons also seems to conflict with Milunicová et al.'s suggestion that a combination of non-tasting and female hormone levels may be protective. Bartoshuk (2000b) attributes the divergent findings to the fact that they were conducted in very different cultures. She noted that the culture dictates the available foods and preparation methods, and therefore tasters might be less at risk in some cultures and more risk in others. Neither study noted whether the cancer patients had already received medical treatment or specified what this was. Both chemotherapy and radiation therapy produce clear losses of taste and olfaction (Bartoshuk, 1990) and therefore could bias sensory responses.

Drewnowski et al. (1999a, 2000) examined PROP sensitivity, food likes/dislikes and intake in women diagnosed with breast cancer before they received any medical or nutritional intervention, and in a control group who were diagnosed as cancer free. In contrast to both Milunicová et al. and Ahuja et al.'s findings, the two groups did not differ in their sensory responses to PROP nor in their food likes/dislikes, energy and nutrient intakes, body mass index, or amount of body fat.

This present study aimed to explore whether taste acuity for 6-n-propylthiouracil acts as genetic marker for coronary heart disease. Levels of PROP acuity in groups with and without coronary heart disease were compared to see if tasting/non-tasting is protective. The relationships between PROP tasting ability and liking/disliking of foods, alcoholic drinks and cigarettes, as well as smoking and drinking habits were also examined.

5.3 Method

5.3.1 Participants

The majority of participants were recruited from five coronary support groups in the Birmingham area. Additional men without CHD, and aged 60 or more, had to be recruited to equal the number of men with CHD and to match for age. Their responses were obtained via post through poster advertisements and requests to pensioner action groups. Two hundred and nineteen individuals completed the questionnaire and the taste test. CHD was defined as having had a previous heart attack, having angina or having a diagnosis of CHD from a medical practitioner. Individuals with congenital or other heart problems were not eligible. The sample comprised 81 men with CHD (49 - 82 years; mean age: 66.3, SD: 6.7 years); 81 men with no history of CHD (47 - 88 years; mean age: 66.1, SD: 7.7 years); 26 women with CHD (45 - 80 years; mean age: 65.6, SD: 7.8 years); 31 women with no history of CHD (44 - 78 years; mean age: 64.7, SD: 7.8 years).

5.3.2 Materials

5.3.2.1 PROP paper

Whatman number one (30 mm diameter) circular filters paper impregnated with PROP were used to measure PROP acuity. A saturated solution was made by adding 5g of PROP to filtered water that was heated to near boiling, and stirred using a magnetic stirrer. The filter papers were dipped into the solution and left to dry on aluminium foil. Small glassine envelopes were used to protect each paper and to aid administration. Samples were prepared no more than a week before presentation.

Responses to the PROP paper were measured using the General Labelled Magnitude Scale (gLMS; Bartoshuk et al., 2000a, Bartoshuk et al., 2000b, Bartoshuk et al., 2001), a slightly modified version of the Labelled Magnitude Scale (Green, Shaffer, and Gilmore, 1993; Figure 1.1 in Section 1.9 of Chapter One). The gLMS uses "strongest imaginable sensation of any kind" as the top anchor which refers to all sensory modalities rather than "strongest imaginable" which refers only to oral sensations. All other characteristics of the scale remain identical. The line is vertical with category labels in a quasi-logarithmic distribution, (barely detectable; weak; moderate; strong; very strong). It is a category ratio scale that yields data with ratio level properties.

5.3.2.2 Questionnaire

The questionnaire consisted of an informed consent form, a single page of questions and a page of instructions and response scale for the taste test.

Participants were asked to state: their age and sex; their three favourite foods; favourite alcoholic drink; and the three foods they most dislike. Liking for cigarettes was rated on a 100 mm horizontal line scale from "not at all" on the far left (0 mm) and "extremely" at 75 mm. They were asked to respond even if they don't smoke but had tried cigarettes, or to tick a box instead if they had never tried a cigarette. The participants were also asked how many units of alcohol they drank per week ("1 unit = half a pint of lager/beer; single spirit measure; small glass of wine"), whether they smoked, and if so how many they smoked per day.

Two slightly modified versions of the questionnaire were used; one for individuals with CHD and one for the controls. There were two minor differences in the questions: individuals with CHD were asked to state the nature of their heart problem (i.e. previous heart attack or angina); and asked about their smoking and drinking habits before, rather than after, they were diagnosed as having a heart problem.

For the taste test, the participants were instructed that the line scale "can describe every sensation you've ever experienced in your whole life. The label at the top 'strongest imaginable sensation of any kind' describes the strongest sensations you have ever experienced. For example, looking directly at the sun, the worst toothache you have ever had, the sound of a jet plane flying just over your head, a burn from a cooker ring". They were asked to put the filter paper on the front of their tongue and keep it there for about thirty seconds. They had to think about how strong or weak it tasted and to put a mark on the line that corresponded to this, remembering that the upper point corresponded with the strongest imaginable sensation they had ever experienced.

Cut-off points at 11 mm and 45 mm were used. Individuals who placed their rating between 0 (bottom of the scale) up to, and including, 11mm were classified as non-tasters, between 12 mm and 45 mm as medium tasters, and between 45 mm and 100 mm as supertasters. These were modified from cut-off points used in the 100 mm Labelled Magnitude Scale (15 and 71; J. Delwich, personal communication). The cut-off points were lowered since the upper label in the LMS "strongest imaginable oral sensation" constrains PROP ratings more than "strongest imaginable sensation of any kind" in the gLMS, especially for supertasters.

5.3.3 Procedure

At the coronary support groups, the group was told the nature of the study before they were asked to participate. Spouses without heart problems were also encouraged to take part. Drinks were postponed until after the taste test was completed. The group were also asked to take a questionnaire home to give to anyone without heart problems. Debriefing was given, and interested individuals informed of their taster status.

Where participants responded to recruitment posters a covering letter told them the nature of the study. The taste sample and the appropriate version of the questionnaire were also posted, along with an self-addressed envelope and debriefing sheet which they were asked not to read until after they had filled out the questionnaire. They were also instructed not to eat, drink, smoke, chew gum, or brush their teeth for at least an hour before tasting the filter paper.

5.3.4 Statistics

The effect of CHD and sex on PROP ratings was examined using a two-way between subjects ANOVA.

Three three-way MANOVAs were used to analyse the effects of CHD, PROP taster status, and sex on favourite foods, most disliked foods, and favourite alcoholic drink. The listed foods and drinks were put into categories for each individual. The data used as the dependent variables were the number of times each category was mentioned by each group of people. The effect of CHD, PROP taster status, and sex on hedonic ratings of cigarettes was also determined using a three-way ANOVA.

Three non-parametric tests were employed instead of a three-way ANOVA to study the effects of CHD, PROP taster status, and sex on self-reported number of cigarettes smoked per day since the homogeneity of variance assumption was violated for these data. A Kruskal-Wallis test was used to look at the effect of PROP taster status on number of cigarettes smoked per day, and two Mann-Whitney tests to examine the effects of sex and CHD. Potential interactions between CHD, PROP taster status, and sex were described using cell medians and interaction plots. These analyses were also used as an alternative to a three-way ANOVA when the homogeneity of variance assumption was again violated, to determine the effects of CHD, PROP taster status, and sex on the self-reported units of alcohol drank per week.

Since only 25% of the sample were smokers, cell frequencies were described and three Chi-square tests reported: PROP taster status x smoker status; CHD x smoker status; sex x smoker status.

5.4 Results

5.4.1 Frequencies of Non-tasters, Medium Tasters, and Supertasters

There were 102 non-tasters, 79 medium tasters, and 38 supertasters (NTs = 46.6%; MTs = 36.1%, STs = 17.4%). Although there was a significant overall difference in age between taster groups ($F[1, 216] = 3.442$, $p < 0.05$), there were no significant differences between all combinations of the three taster groups when Scheffé post-hoc tests were performed (Table 5.1).

TABLE 5.1
MEAN AGE AMONG NON-TASTERS, MEDIUM TASTERS, AND SUPERTASTERS

PROP Taster Status	Mean Age (SD)
Non-tasters (N = 102)	66.4 (7.2)
Medium tasters (N = 79)	66.6 (7.6)
Supertasters (N = 38)	63.1 (6.4)
Total (N = 219)	65.9 (7.3)

5.4.2 Distributions of PROP Ratings

The PROP ratings in the whole sample of older adults were positively skewed, indicating that a high proportion of participants gave low PROP ratings and were relatively insensitive to the taste of PROP (Figure 5.1). Visual inspection of Figures 5.2 and 5.3 indicates that the range of PROP ratings was greater among participants without CHD, compared to those with CHD, suggesting the occurrence of more individuals with heightened PROP acuity among the control group.

Positive skew was observed among the males, both as a whole (Figure 5.4) and when subdivided into males with and without CHD (Figures 5.6 and 5.7), but not among the females where a clearer bimodal distribution was more evident (Figures 5.5, 5.8, and 5.9).

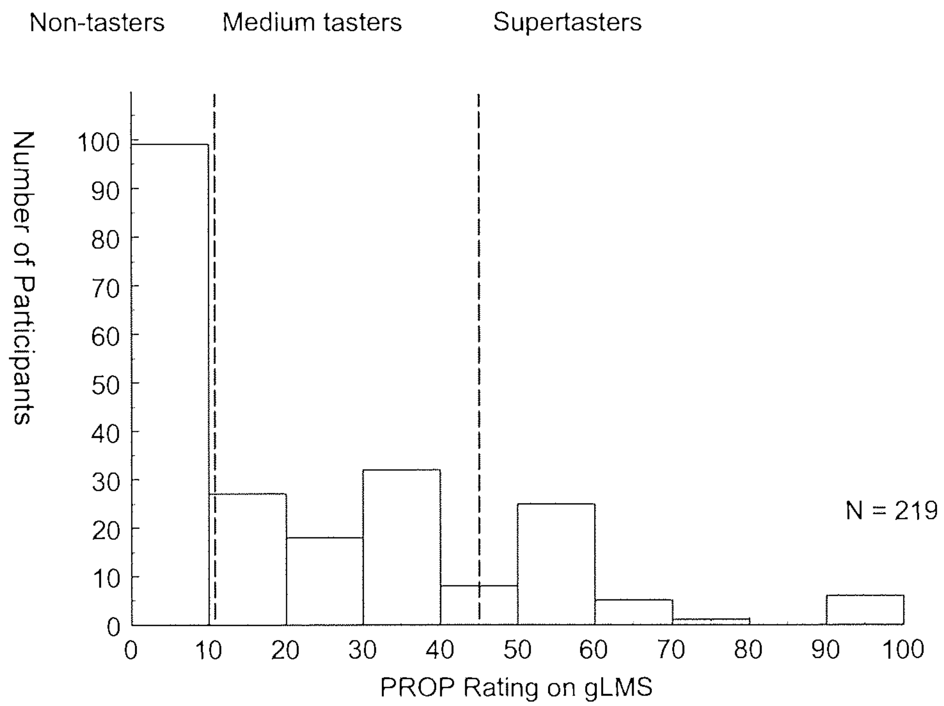

FIGURE 5.1
DISTRIBUTION OF PROP RATINGS IN WHOLE SAMPLE

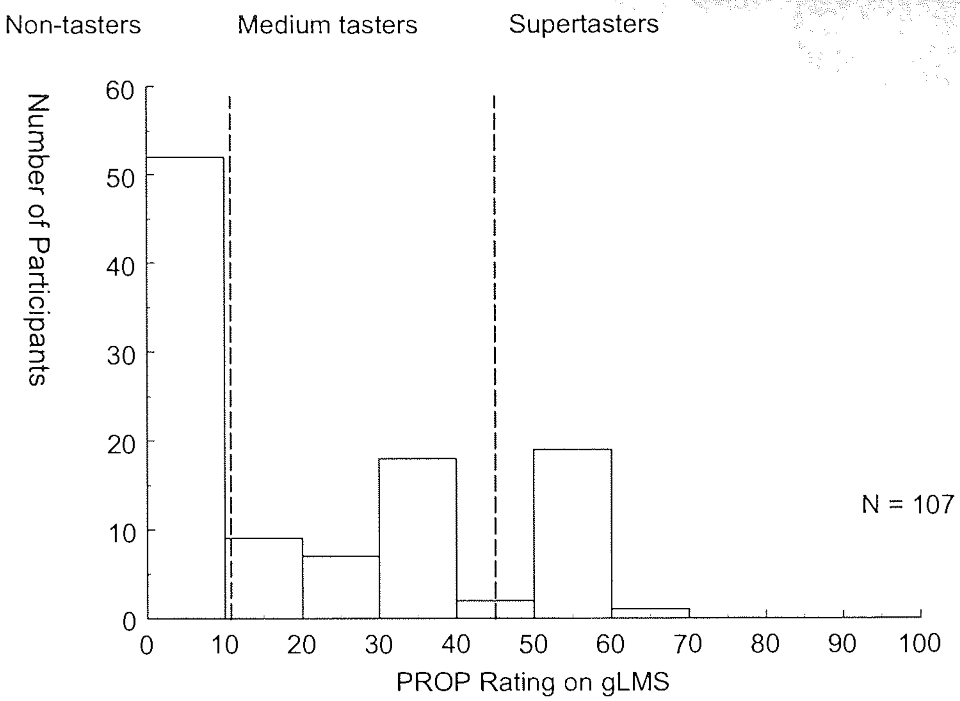

FIGURE 5.2
DISTRIBUTION OF PROP RATINGS IN PARTICIPANTS WITH CHD

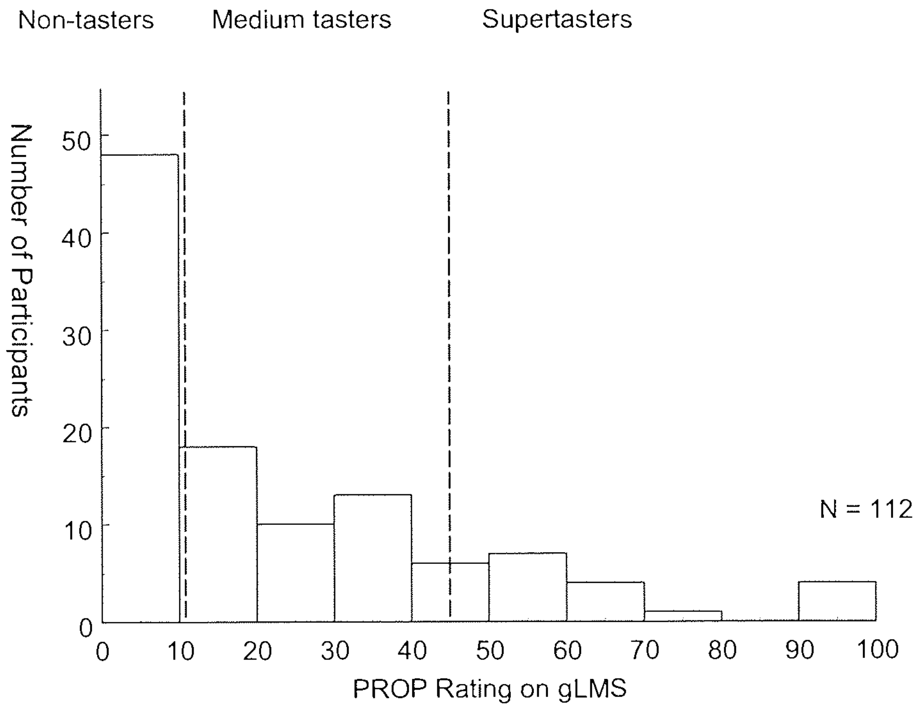

FIGURE 5.3
DISTRIBUTION OF PROP RATINGS IN PARTICIPANTS WITHOUT CHD

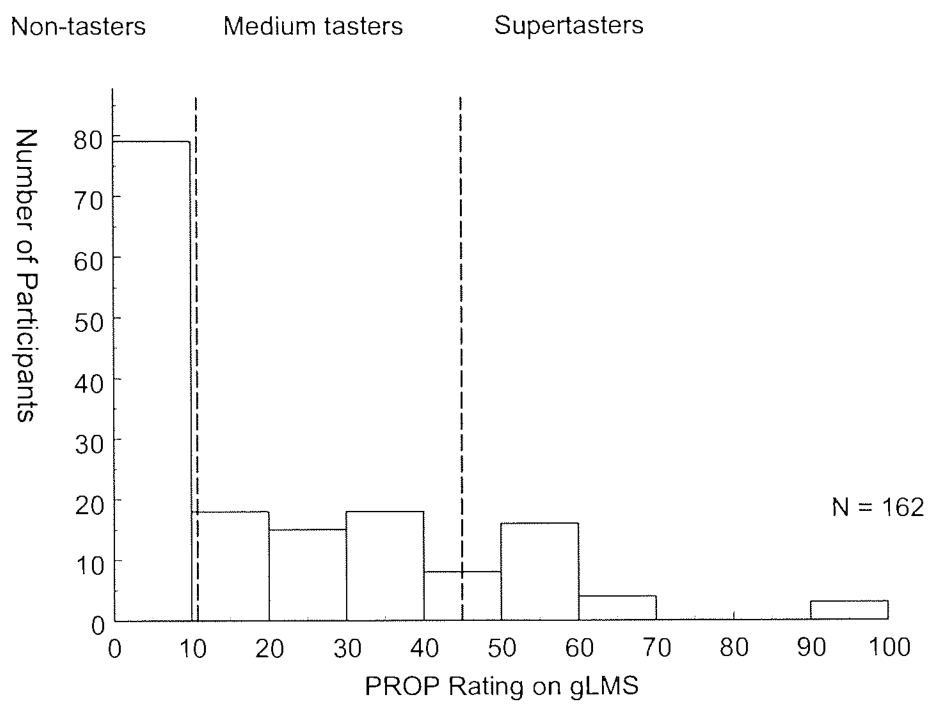

FIGURE 5.4
DISTRIBUTION OF PROP RATINGS IN MEN

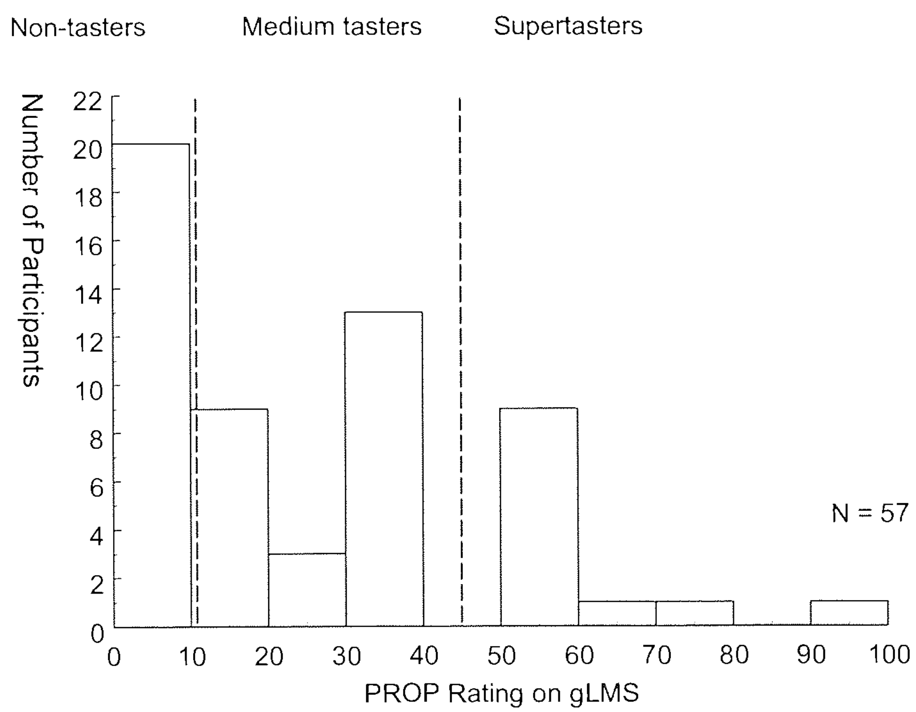

FIGURE 5.5
DISTRIBUTION OF PROP RATINGS IN WOMEN

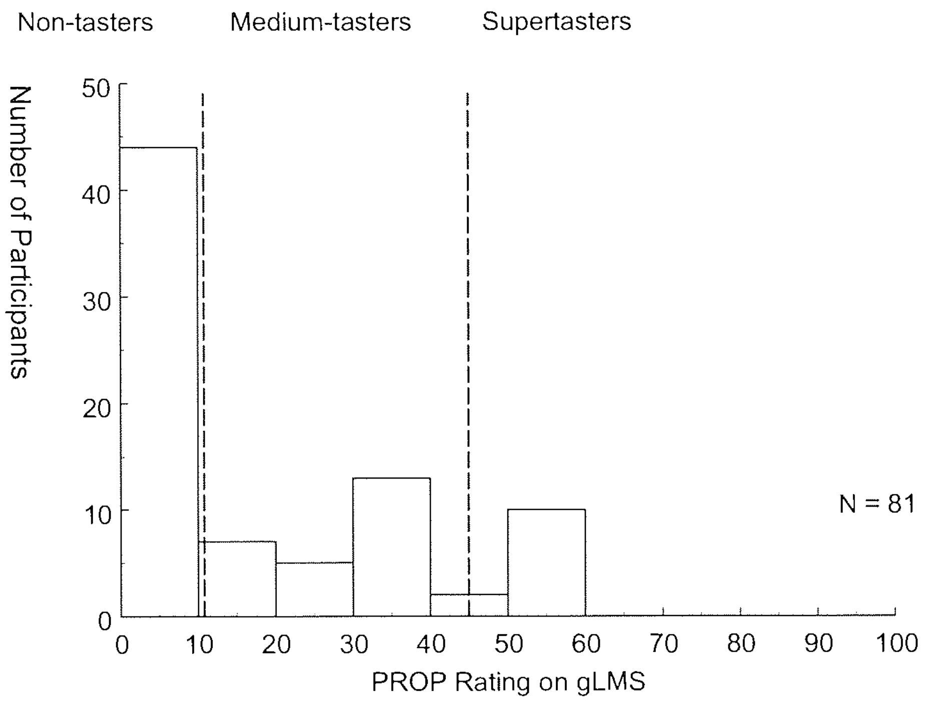

FIGURE 5.6
DISTRIBUTION OF PROP RATINGS IN MEN WITH CHD

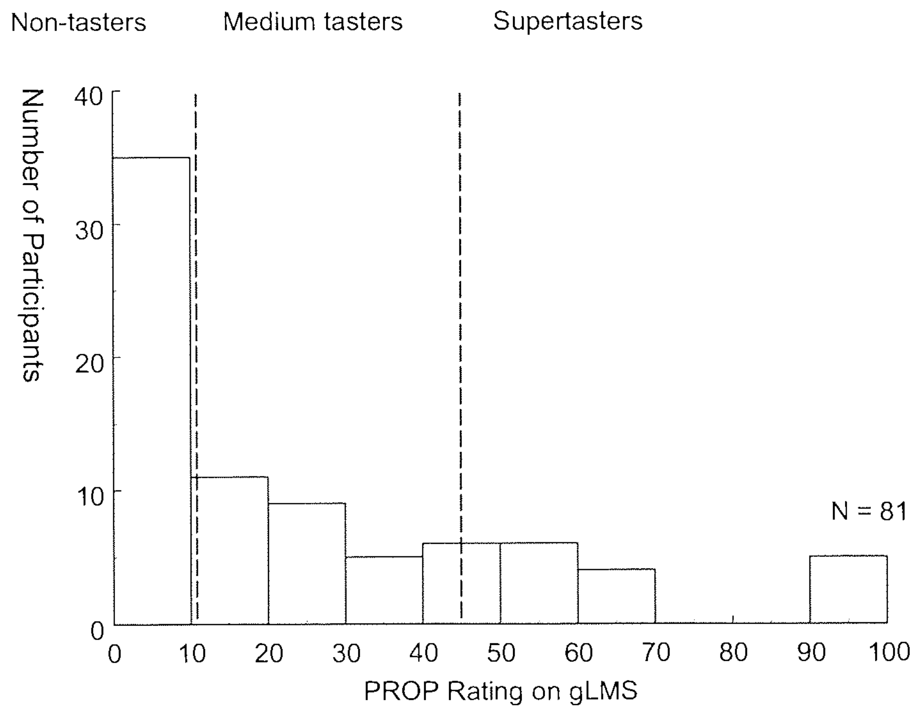

FIGURE 5.7
DISTRIBUTION OF PROP RATINGS IN MEN WITHOUT CHD

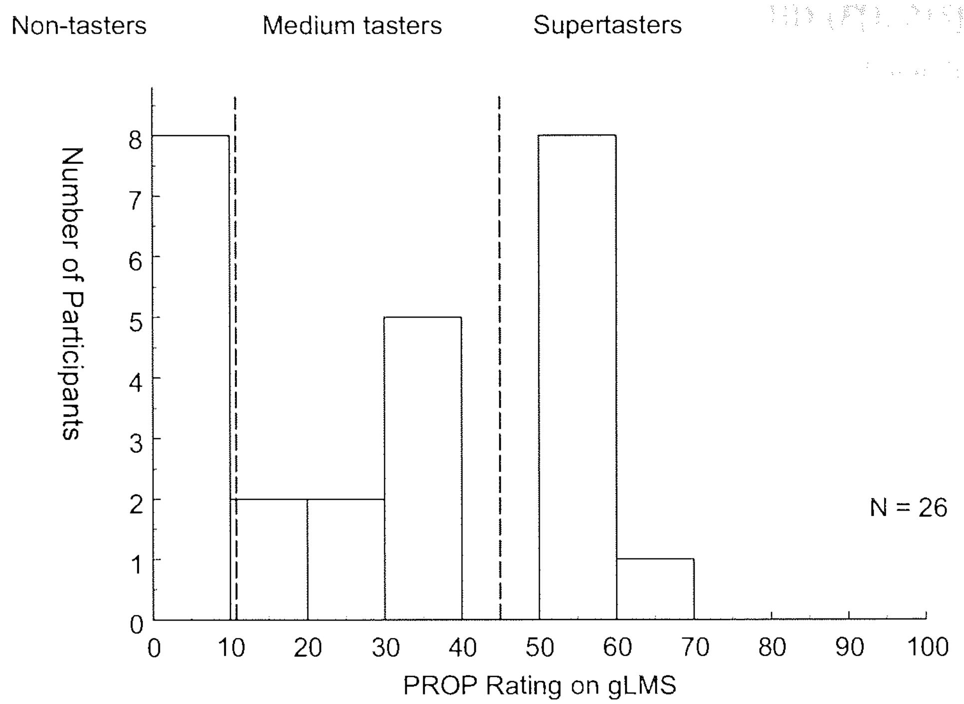

FIGURE 5.8
DISTRIBUTION OF PROP RATINGS IN WOMEN WITH CHD

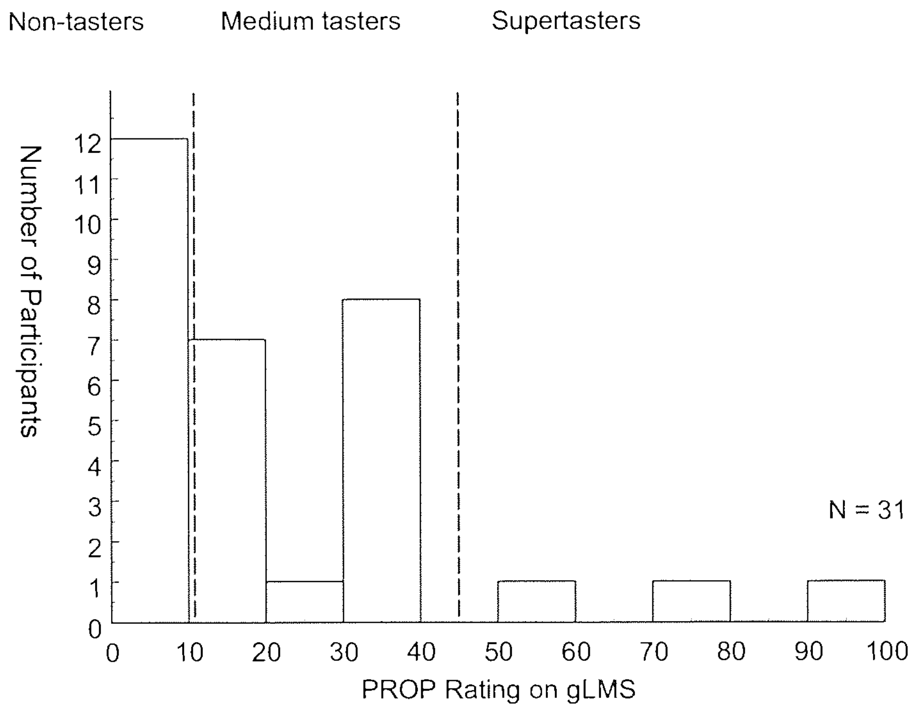

FIGURE 5.9
DISTRIBUTION OF PROP RATINGS IN WOMEN WITHOUT CHD

5.4.3 PROP Tasting Ability Among Groups With and Without Heart Disease

There were no main effects of presence or absence of CHD ($F[1, 215] = 0.007$, $p > 0.05$) or sex ($F[1, 215] = 1.996$, $p > 0.05$) on PROP acuity, although there was an interaction between CHD and sex ($F[1, 215] = 4.882$, $p < 0.05$; Figure 5.10; Table 5.2). Men with heart disease had a lower mean PROP rating than men without heart disease. Conversely, women with heart disease rated PROP as tasting *more* intense than women without heart disease. Men with CHD had a lower PROP intensity rating than women with CHD. PROP ratings were more similar among men and women without CHD.

TABLE 5.2
MEAN PROP RATINGS AMONG MEN AND WOMEN WITH AND WITHOUT HEART DISEASE

	Mean PROP Rating (SD)		Total
	Males (N = 162)	Females (N = 57)	
CHD (N = 107)	17 (19.4)	30 (22.6)	21 (20.9)
No CHD (N = 112)	25 (26.4)	22 (23.1)	24 (25.5)
Total	21 (23.4)	26 (23.0)	22 (23.4)

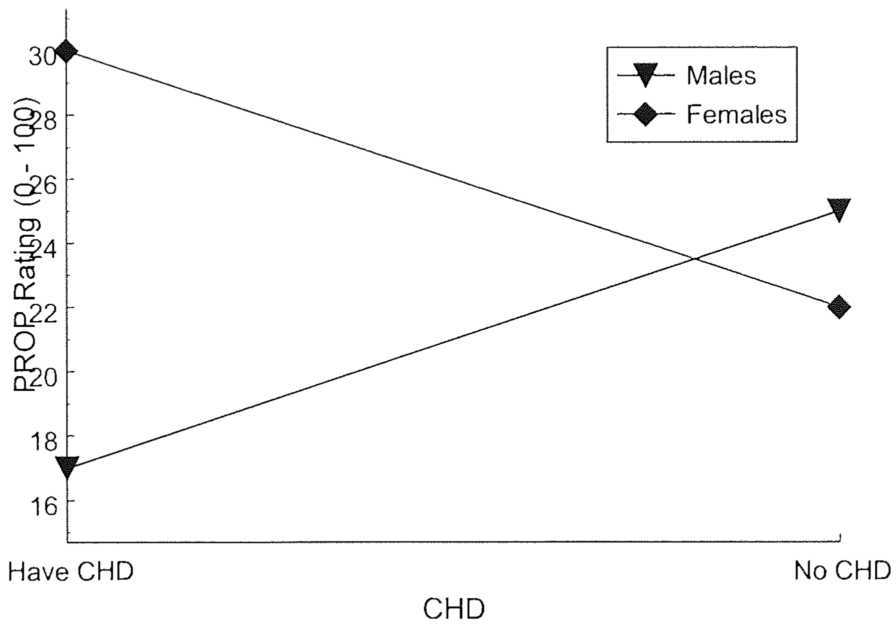

FIGURE 5.10
INTERACTION BETWEEN SEX AND CHD ON PROP INTENSITY RATINGS

5.4.4 Effect of PROP Acuity, Heart Disease, and Sex on Favourite Foods

Each of the three listed favourite foods were categorised into food types (Table 5.3), and the number of times a food category was listed was computed for each participant. The maximum mean number of times each food category could be listed as a favourite food was three since a participant could list a maximum of three foods.

Statistics are not given for categories named as pulses, soup, Chinese food, and breakfast cereals as they were rarely listed as favourite foods. "Starches" included bread, pasta, rice and potatoes, "high fat foods" included crisps, chips, and "spicy food" included foods such as curries.

TABLE 5.3
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "FAVOURITE FOOD" FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS (max. 3)

Type of Food	Non-tasters (SD) N = 102	Medium Tasters (SD) N = 79	Supertasters (SD) N = 38
Red Meat	.81 (.79)	.65 (.66)	.87 (.78)
Poultry	.29 (.46)	.39 (.49)	.39 (.59)
Fish	.43 (.52)	.44 (.50)	.24 (.43)
Desserts/Sweet Snacks	.16 (.37)	.23 (.55)	.26 (.60)
Fruit	.21 (.43)	.11 (.32)	.11 (.31)
Vegetables	.25 (.44)	.25 (.47)	.24(.59)
Starches	.25 (.52)	.28 (.53)	.34 (.53)
High Fat Food	.14 (.35)	.14 (.38)	.21 (.53)
Spicy Food	.12 (.35)	.15 (.40)	.39 (1.79)
Dairy Products	.19 (.39)	.15 (.36)	.13 (.34)

The descriptive statistics in Table 5.3 show that the category listed most often as a favourite food was red meat, and non-tasters and supertasters cited it as a favourite food more often than medium tasters. Medium tasters and supertasters listed poultry and desserts/sweet snacks more often, and fruit less often, as a favourite food than non-tasters. Supertasters listed fish less often and spicy foods most often, as a favourite food than non-tasters and medium tasters did (Table 5.3).

There was no multivariate effect of PROP taster status on favourite foods ($F[20, 398] = 1.521$, $p > 0.05$) although Pillai's criterion approached significance ($p = 0.07$). The

Stepdown F-tests were significant for red meat ($F[2, 207] = 3.582$, $p < 0.05$) and fruit ($F[2, 206] = 4.927$, $p < 0.05$), but the corresponding univariate F tests were not significant at an alpha level of 0.005 (red meat: $F[2, 207] = 3.582$, $p > 0.005$; fruit: $F[2, 207] = 3.980$, $p > 0.005$).

TABLE 5.4
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "FAVOURITE FOOD" FOR GROUPS WITH AND WITHOUT HEART DISEASE (max.3)

Type of Food	Heart Disease (SD) N = 107	No Heart Disease (SD) N = 112
Red Meat	.76 (.78)	.77 (.72)
Poultry	.38 (.51)	.31 (.48)
Fish	.44 (.50)	.37 (.50)
Desserts/Sweet Snacks	.20 (.50)	.21 (.47)
Fruit	.19 (.42)	.13 (.33)
Vegetables	.29 (.51)	.21 (.43)
Starches	.20 (.44)	.35 (.58)
High Fat/Fast Food	.14 (.37)	.16 (.41)
Spicy Food	.11 (.32)	.24 (1.10)
Dairy Products	.17 (.38)	.16 (.37)

Groups with and without heart disease listed foods in most of the food categories as favourite foods on similar number of occasions, although those without heart disease listed starches and spicy foods among their favourite foods more often than those with heart disease (Table 5.4). There was no multivariate effect of presence or absence of CHD on favourite foods ($F[10, 198] = 1.065$, $p > 0.05$). Although the stepdown F value for starches was significant ($F[1, 200] = 4.087$, $p < 0.05$), the corresponding univariate test was not significant at an alpha level of 0.005 ($F[1, 207] = 5.121$, $p > 0.005$), indicating no effect of presence or absence of CHD on frequency of listing starches as a favourite food.

Men listed meat and spicy foods as favourite foods more often than women, whereas women listed poultry, fish and fruit more often than men (Table 5.5). There was an overall multivariate effect of sex on favourite foods ($F[10, 198] = 2.247$, $p < 0.05$). Stepdown tests were significant for red meat ($F[1, 207] = 6.222$, $p < 0.05$) and fruit ($F[1, 206] = 7.354$, $p < 0.05$) and poultry ($F[1, 204] = 4.413$, $p < 0.05$), although the only corresponding univariate value that was significant at an alpha level of 0.005 was for fruit ($F[1, 207] = 10.320, p < 0.005$).

TABLE 5.5
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "FAVOURITE FOOD" FOR MALES AND FEMALES (max. 3)

Type of Food	Males SD N = 162	Females (SD) N = 57
Red Meat	.17 (.37)	.16 (.37)
Poultry	.31 (.48)	.44 (.54)
Fish	.36 (.49)	.53 (.50)
Desserts/Sweet Snacks	.20 (.46)	.21 (.56)
Fruit	.10 (.33)	.30 (.46)
Vegetables	.24 (.48)	.28 (.45)
Starches	.27 (.50)	.30 (.60)
High Fat/Fast Food	.16 (.38)	.12 (.43)
Spicy Food	.22 (.94)	.07 (.26)
Dairy Products	.17 (.37)	.16 (.37)

There was a significant interaction between the effects of PROP taster status, CHD, and sex on favourite foods ($F[20, 398] = 1.904, p < 0.05$). Stepdown tests were significant for poultry ($F[2, 204] = 6.533, p < 0.05$) and dairy products ($F[2, 198] = 3.477, p < 0.05$), and approached significance for starches ($F[2, 200] = 2.955, p = 0.054$). None of the corresponding univariate values were significant at an alpha value of 0.005, although the univariate F test for poultry approximated significance ($F[2, 207] = 5.306, p = 0.006$). Interaction plots for poultry (Figure 5.11) show that, among men with CHD and women without CHD, supertasters were more likely to list poultry as a favourite food than non-tasters and medium tasters. There were no PROP effects for men without CHD, and among women with CHD, supertasters were least likely to list poultry as a favourite food. There were no interactions between the effects of CHD and sex ($F[10, 198] = 1.254, p > 0.05$), PROP taster status and sex ($F[20, 398] = 1.360, p > 0.05$), or PROP taster status and CHD ($F[20, 398] = 1.313, p > 0.05$) on favourite foods.

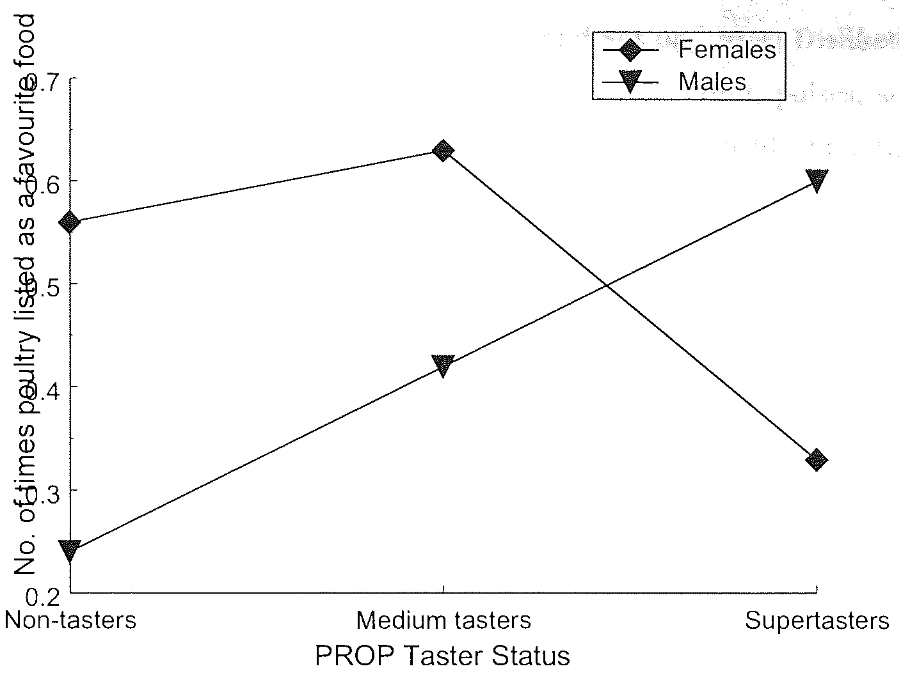

FIGURE 5.11.A PARTICIPANTS WITH CHD

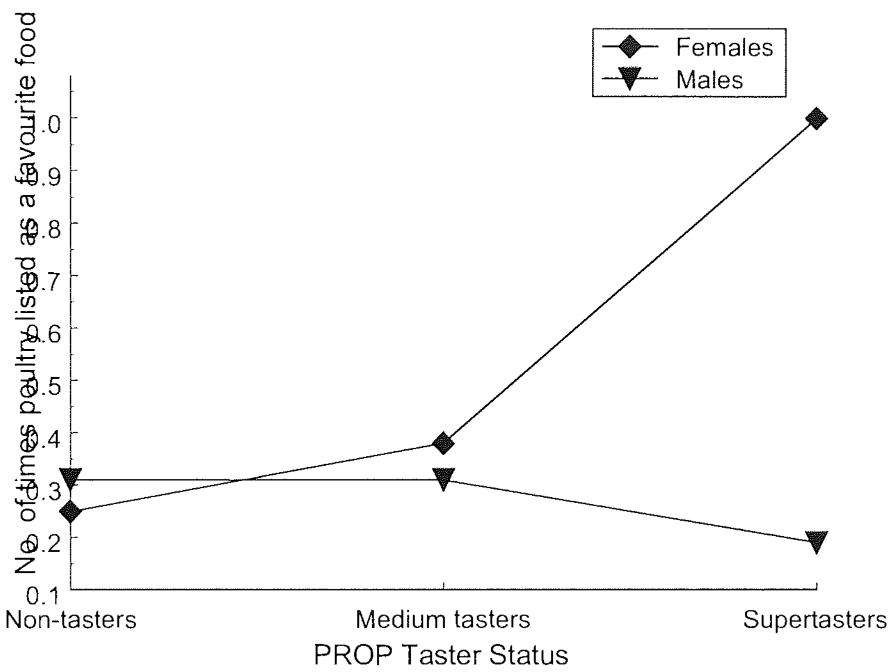

FIGURE 5.11.B PARTICIPANTS WITHOUT CHD

FIGURE 5.11
INTERACTIONS BETWEEN THE EFFECTS OF PRESENCE OR ABSENCE OF CHD, PROP TASTER STATUS, AND SEX ON NUMBER OF TIMES POULTRY WAS LISTED AS A FAVOURITE FOOD

5.4.5 Effect of PROP Acuity, Heart Disease, and Sex on "Most Disliked" Foods

Statistics are not given for categories named as poultry, fruit, pulses, soup, Chinese food, and breakfast cereals as they were rarely listed as most disliked foods, yielding ten categories of disliked foods in total (Table 5.6). Seventeen individuals stated that they had no food dislikes whatsoever, 20 could only list one disliked food, and 20 only two disliked foods. Offal was defined as any type of animal entrails such as tripe, faggots and haggis, and unconventional meats were meats not commonly eaten (in Britain) such as rabbit, eels, snails, whale meat, and octopus (all cited). Fish listed as disliked foods tended to be shellfish, which were rarely cited as a favourite type of fish.

TABLE 5.6
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "MOST DISLIKED FOOD" FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS (max. 3)

Type of Food	Non-tasters (SD) N = 102	Medium Tasters (SD) N = 79	Supertasters (SD) N = 38
No Food Dislikes	.62 (1.02)	.54 (.96)	.39 (.72)
Red Meat	.17 (.40)	.14 (.45)	.16 (.37)
(Shell)Fish	.21 (.41)	.27 (.47)	.32 (.53)
Offal/Unconventional meats	.19 (.46)	.20 (.52)	.13 (.41)
Desserts/Sweet Snacks	.10 (.30)	.18 (.50)	.03 (.16)
Vegetables	.44 (.77)	.48 (.64)	.63 (.94)
Starches	.21 (.43)	.16 (.37)	.16 (.37)
High Fat/Fast Food	.22 (.50)	.22 (.41)	.26 (.55)
Spicy Food	.51 (.64)	.37 (.56)	.37 (.54)
Dairy Products	.07 (.30)	.11 (.36)	.13 (.34)

Non-tasters were more likely to note that they had no food dislikes than medium tasters and supertasters (Table 5.6). Supertasters listed (shell)fish and vegetables as most disliked foods more often than non-tasters and medium tasters. However, there was no multivariate effect of PROP taster status on listings of disliked foods ($F[20, 398] = 0.744$, $p > 0.05$).

TABLE 5.7
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "MOST DISLIKED FOOD" FOR GROUPS WITH AND WITHOUT HEART DISEASE (max. 3)

Type of Food	Heart Disease (SD) N = 107	No Heart Disease (SD) N = 112
No Food Dislikes	.79 (1.04)	.32 (.79)
Red Meat	.17 (.47)	.14 (.35)
(Shell)Fish	.24 (.47)	.25 (.43)
Offal/Unconventional meats	.16 (.44)	.21 (.50)
Desserts/Sweet Snacks	.10 (.31)	.13 (.43)
Vegetables	.39 (.68)	.58 (.81)
Starches	.14 (.35)	.22 (.44)
High Fat/Fast Food	.16 (.39)	.29 (.54
Spicy Food	.41 (.57)	.46 (.63)
Dairy Products	.10 (.33)	.10 (.33)

The descriptive statistics show that participants with heart disease were more likely to report having no food dislikes, and less likely to list vegetables and high fat/fast foods among their most disliked foods than those without heart disease (Table 5.7). There was no multivariate effect of presence or absence of CHD on listings of disliked foods ($F[10, 198] = 0.831, p > 0.05$).

TABLE 5.8
MEAN NUMBER OF TIMES EACH FOOD CAREGORY WAS LISTED AS A "MOST DISLIKED FOOD" FOR MALES AND FEMALES (max. 3)

Type of Food	Males (SD) N = 162	Females (SD) N = 57
No Food Dislikes	.56 (.99)	.53 (.83)
Red Meat	.15 (.37)	.18 (.50)
(Shell)Fish	.21 (.41)	.35 (.55)
Offal/Unconventional meats	.13 (.39)	.33 (.64)
Desserts/Sweet Snacks	.11 (.37)	.12 (.38)
Vegetables	.54 (.80)	.35 (.61)
Starches	.21 (.42)	.11 (.31)
High Fat/Fast Food	.22 (.49)	.23 (.46)
Spicy Food	.44 (.62)	.42 (.53)
Dairy Products	.09 (.31)	.12 (.38)

Women were more likely to note (shell)fish and offal/unconventional meats, and less likely to list vegetables and starches among their most disliked foods than men (Table

5.8). There was no overall multivariate effect of sex on most disliked ($F[10, 198] = 1.527$, $p > 0.05$). Stepdown F values were significant for starches ($F[1, 204] = 3.875$, $p < 0.05$) and (shell)fish ($F[1, 199] = 4.179$, $p < 0.05$) but the corresponding univariate values were not significant (starches: $F[1, 207] = 2.821$, $p > 0.005$; (shell)fish: $F[1, 207] = 5.720$, $p > 0.005$).

There were no interactions between the effects of CHD and sex ($F[10, 198] = 0.695$, $p > 0.05$), PROP taster status and sex ($F[20, 398] = 1.226$, $p > 0.05$), PROP taster status and CHD ($F[20, 398] = 0.917$, $p > 0.05$), or PROP taster status and CHD and sex ($F[20, 398] = 1.140$, $p > 0.05$) on disliked foods.

5.4.6 Effect of PROP Acuity, Heart Disease, and Sex on Favourite Alcoholic Drink

Types of alcohol cited as favourite alcoholic drinks included lager/beer, spirits, spirits with a mixer, and wine. Since 54 participants stated that they did not have a favourite alcoholic drink, usually as they did not consume alcohol, a "none" category was also used. Statistics are not given for categories named as lager and fruit cordial, bitter, cider, cider and fruit, and gin/vodka tonic as they were rarely listed as favourite alcoholic drinks.

TABLE 5.9
NUMBER OF TIMES EACH BEVERAGE WAS LISTED AS A "FAVOURITE ALCOHOLIC DRINK" FOR NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

	Non-tasters (%) N = 102	Medium Tasters (%) N = 79	Supertasters (%) N = 38
None	35 (16)	13 (17)	6 (18)
Lager/beer	40 (18)	13 (17)	7 (16)
Spirit	62 (28)	24 (30)	12 (32)
Spirit and mixer	9 (4)	2 (3)	4 (11)
wine	48 (22)	20 (25)	4 (11)

Supertasters cited spirits with a mixer more often, and wine less often, as their favourite alcoholic drink than non-tasters and medium tasters (Table 5.9). However, there was no significant association between PROP taster status and favourite alcoholic drink (χ^2 = 7.055, $df = 8, p > 0.05$).

TABLE 5.10
NUMBER OF TIMES EACH BEVERAGE WAS LISTED AS A "FAVOURITE ALCOHOLIC DRINK" FOR GROUPS WITH AND WITHOUT HEART DISEASE

Type of Alcoholic Drink	Heart Disease (SD) N = 107	No Heart Disease (SD) N = 112
None	14 (13)	21 (19)
Lager/beer	25 (23)	15 (13)
Spirit	30 (28)	32 (29)
Spirit and mixer	5 (5)	4 (4)
wine	18 (17)	30 (27)

Those with heart disease were more likely to cite lager/beer, and less likely to cite wine as their favourite alcoholic drink, than those without heart disease (Table 5.10). There was no significant association between presence/absence of heart disease on favourite alcoholic drink (χ^2 = 6.578, $df = 4, p > 0.05$).

TABLE 5.11
NUMBER OF TIMES EACH BEVERAGE WAS LISTED AS A "FAVOURITE ALCOHOLIC DRINK" FOR MALES AND FEMALES

Type of Alcoholic Drink	Males (SD) N = 162	Females (SD) N = 57
None	27 (17)	8 (14)
Lager/beer	39 (24)	1(2)
Spirit	44 (27)	18 (32)
Spirit and mixer	6 (4)	3 (5)
wine	28 (17)	20 (35)

The males cited lager/beer as their favourite alcoholic drink more often than women, and cited wine less often (Table 5.11). There was no a significant association between PROP taster status and favourite alcoholic drink (χ^2 = 18.432, $df = 4, p < 0.05$).

5.4.7 Effect of PROP Acuity, Heart Disease, and Sex on Self-reported Alcohol Consumption

The self-reported number of units of alcohol currently consumed was used as the dependent variable for participants without CHD, whereas for the participants with CHD the estimated number of units *before* they knew they had heart disease was used. This was to ensure a measure of alcohol intake before changes might have been made to promote their health, which would have been less likely to be influenced by taste.

A three-way ANOVA could not be performed since the homogeneity of variance assumption was violated, necessitating the use of non-parametric tests. There was no effect of taster status ($H = 2.510$, df = 2, $p > 0.05$), or presence or absence of CHD ($U = 5820.50$, $p > 0.05$) on self-reported weekly alcohol consumption. However, there was a significant effect for sex ($U = 2905.50$, $p < 0.05$), with men reporting drinking more units of alcohol per week than women (Table 5.12).

TABLE 5.12
MEDIAN ESTIMATED NUMBER OF ALCOHOL UNITS DRUNK PER WEEK, ACCORDING TO PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD, AND SEX

Variable	Level	Alcohol units (Interquartile Range)
PROP Taster Status	Non-tasters (N = 100)	3.0 (8.5)
	Medium Tasters (N = 77)	3.75 (6.3)
	Supertasters (N = 38)	2.0 (6.3)
CHD	Have CHD (N = 105)	3.0 (6.3)
	No CHD (N = 110)	2.5 (7.0)
Sex	Males (N = 160)	4.0 (9.0)
	Females (N = 55)	1.0 (4.0)

TABLE 5.13
MEDIAN ESTIMATED NUMBER OF ALCOHOL UNITS DRANK PER WEEK, ACCORDING TO PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD, AND SEX - CELL MEDIANS

PROP Taster Status	CHD	Sex	N	Alcohol units (Interquartile Range)
Non-tasters	Have CHD	Male	45	4 (9.0)
	Have CHD	Female	9	2 (3.0)
	No CHD	Male	36	4 (11.5)
	No CHD	Female	11	2 (6.0)
Medium Tasters	Have CHD	Male	25	6 (8.5)
	Have CHD	Female	8	0 (4.8)
	No CHD	Male	29	4 (11.5)
	No CHD	Female	16	2 (2.8)
Supertasters	Have CHD	Male	10	3 (9.8)
	Have CHD	Female	9	0 (3.0)
	No CHD	Male	16	2 (10.9)
	No CHD	Female	3	0 (0.0)

Among males and females who did not have CHD, non-tasters and medium tasters reported drinking similar amounts of alcohol, and more than supertasters (Table 5.13; Figure 5.12.B). Less uniform patterns were observed among those with CHD (Table 5.13; Figure 5.12.A). Female non-tasters reported consuming more alcohol than medium tasters and supertasters. Among the men, it was the medium tasters who reported the highest consumption.

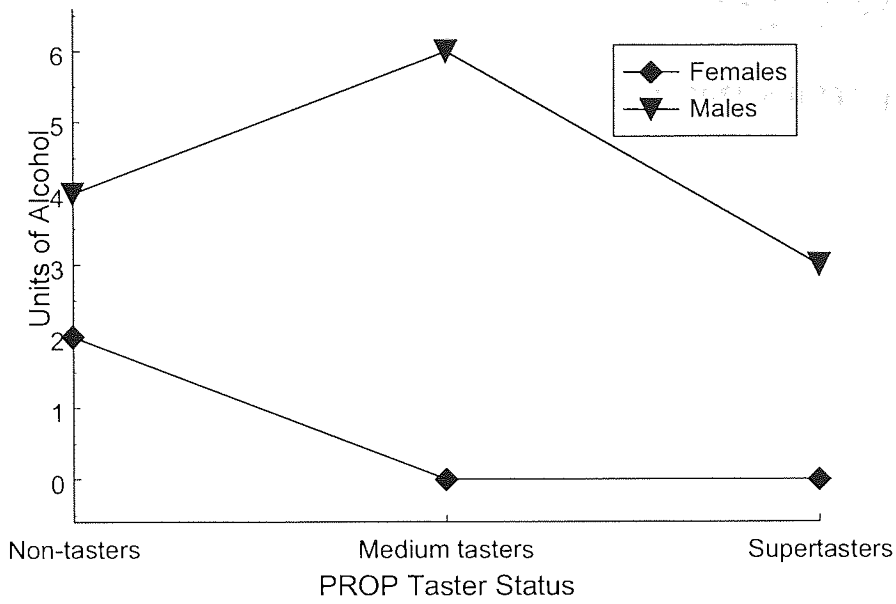

FIGURE 5.12.A PARTICIPANTS WITH CHD

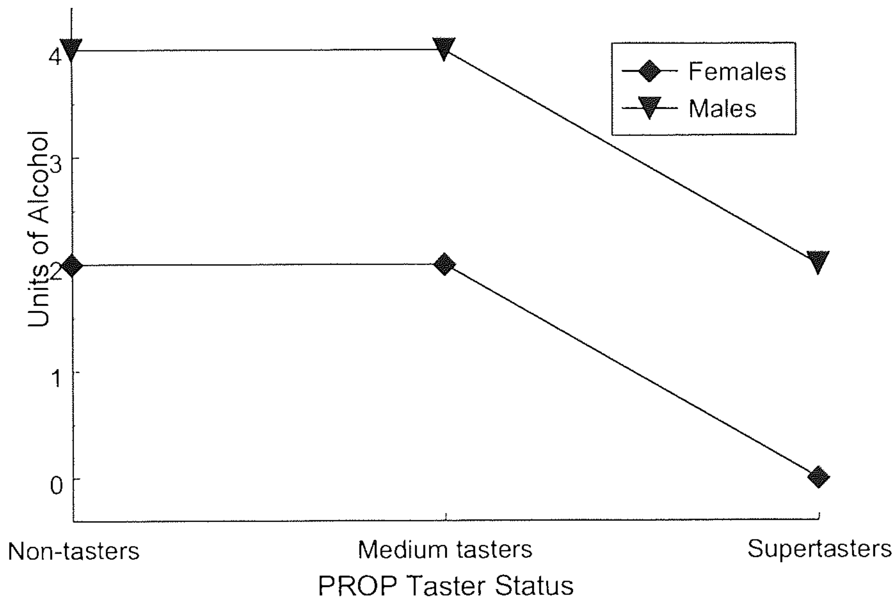

FIGURE 5.12.B PATICIPANTS WITHOUT CHD

FIGURE 5.12
INTERACTIONS BETWEEN THE EFFECTS OF PRESENCE OR ASENCE OF CHD, PROP TASTER STATUS, AND SEX ON ESTIMATED WEEKLY CONSUMPTION OF ALCOHOL (UNITS)

5.4.8 Effect of PROP Acuity, Heart Disease, and Sex on Hedonic Ratings of Cigarettes

There were no main effects of PROP taster status ($F[2, 205] = 0.332$, $p > 0.05$) or presence or absence of heart disease ($F[1, 205] = 0.642$, $p > 0.05$) on hedonic ratings of cigarettes, although there was almost a significant difference between males' and females' ($F[1, 205] = 3.318$, $p = 0.07$) ratings. Women disliked the taste of cigarettes more than males (Table 5.14).

There were no interactions between CHD and sex ($F[1, 205] = 0.138$, $p > 0.05$), CHD and PROP taster status ($F[2, 205] = 0.511$, $p > 0.05$), sex and PROP taster status ($F[2, 205] = 0.400$, $p > 0.05$), or between CHD, sex, and PROP taster status ($F[2, 205] = 0.083$, $p > 0.05$).

TABLE 5.14
MEAN HEDONIC RATINGS OF CIGARETTES ACCORDING TO PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD, AND SEX

Variable	Level	Hedonic Rating of Cigarettes (SD)
PROP Taster Status	Non-tasters (N = 101)	13 (20.0)
	Medium Tasters (N = 79)	11 (20.5)
	Supertasters (N = 37)	14 (24.6)
CHD	Have CHD (N = 105)	13 (22.0)
	No CHD (N = 112)	12 (20.9)
Sex	Males (N = 161)	14 (22.8)
	Females (N = 56)	8 (15.8)

5.4.9 Effects of PROP Taster Status, CHD, and Sex on Smoker/Non-Smoker Status

There were 54 (25%) smokers and 163 (75%) non-smokers in the sample (smoker status missing for 2 participants). There were similar proportions of smokers among the three PROP taster groups (Table 5.15). There was a higher proportion of smokers among those with CHD than those without CHD (Table 5.16), and among males than females (Table 5.17).

TABLE 5.15

FREQUENCY OF SMOKERS AND NON-SMOKER STATUS AMONG NON-TASTERS, MEDIUM TASTERS AND SUPERTASTERS

	No. of Smokers (%)	No. of Non-smokers (%)	Total (%)
Non-tasters	24 (24%)	76 (76%)	100 (100%)
Medium Tasters	19(24%)	60 (76%)	79 (100%)
Supertasters	11 (29%)	27 (71%)	38 (100%)

TABLE 5.16

FREQUENCY OF SMOKERS AND NON-SMOKER STATUS AMONG GROUPS WITH AND WITHOUT CHD

	No. of Smokers (%)	No. of Non-smokers (%)	Total (%)
Have CHD	41 (38%)	65 (61%)	106 (100%)
No CHD	13 (12%)	98 (88%)	111 (100%)

TABLE 5.17

FREQUENCY OF SMOKERS AND NON-SMOKER STATUS AMONG MALES AND FEMALES

	No. of Smokers (%)	No. of Non-smokers (%)	Total (%)
Males	44 (27%)	117 (72%)	161 (100%)
Females	10 (18%)	46 (81%)	56 (100%)

There was a significant association between presence or absence of CHD and smoker/non-smoker status ($\chi^2 = 19.677$, $df = 1$, $p < 0.05$), but not between sex and smoker status ($\chi^2 = 1.520$, $df = 1$, $p > 0.05$), or PROP taster status and smoker status ($\chi^2 = 0.407$, $df = 2$, $p > 0.05$).

TABLE 5.18
INTERACTIONS BETWEEN PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD AND SEX, AND FREQUENCIES OF SMOKERS AND NON-SMOKERS

Taster Status		Sex	No. of Smokers (%)	No. of Non-smokers (%)	Total (%)
Non-tasters	CHD	Male	15 (33%)	29 (64%)	45 (100%)
	CHD	Female	1 (11%)	8 (89%)	9 (100%)
	No CHD	Male	6 (17%)	30 (83%)	36 (100%)
	No CHD	Female	2 (17%)	9 (75%)	12 (100%)
Medium Tasters	CHD	Male	13 (50%)	13 (50%)	26 (100%)
	CHD	Female	2 (25%)	6 (75%)	8 (100%)
	No CHD	Male	4 (14%)	25 (86%)	29 (100%)
	No CHD	Female	0 (0%)	16 (100%)	16 (100%)
Supertasters	CHD	Male	5 (50%)	5 (50%)	10 (100%)
	CHD	Female	5 (56%)	4 (44%)	9 (100%)
	No CHD	Male	1 (6%)	15 (94%)	16 (100%)
	No CHD	Female	0 (0%)	3 (100%)	3 (100%)

Too many cells had a value of 5 or less to do inferential statistics (Table 5.18). Among both males and females without CHD, there was a higher percentage of smokers among the non-tasters than the supertasters. A pattern in the opposite direction was found for males and females with CHD - supertasters were more likely to be smokers than non-smokers.

5.4.10 Effects of PROP Taster Status, CHD, and Sex on Number of Cigarettes Smoked

The number of cigarettes currently smoked per week was used as the dependent variable for participants without CHD, whereas for the participants with CHD the estimated number smoked *before* they knew they had heart disease was used. This was to ensure a measure of cigarettes smoking before changes might have been made since their diagnosis.

A three-way ANOVA could not be performed since the homogeneity of variance assumption was violated, necessitating the use of non-parametric tests. These were computed for smokers only. There was no effect of taster status ($H = 3.943$, df $= 2$, $p >$ 0.05), or sex ($U = 181.00$, $p > 0.05$) on number of cigarettes smoked per week.

However, there was a significant effect for presence or absence of CHD ($U = 138.00$, $p < 0.05$) with those with CHD smoking more than those without CHD (Table 5.19).

TABLE 5.19
MEDIAN ESTIMATED NUMBER OF CIGARETTES SMOKED PER WEEK, ACCORDING TO PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD, AND SEX

Variable	Level	No. of Cigarettes (Interquartile Range)
PROP Taster Status	Non-tasters (N = 24)	14.0 (10.0)
	Medium Tasters (N = 19)	20.0 (9.0)
	Supertasters (N = 10)	20.0 (26.3)
CHD	Have CHD (N = 40)	20.0 (12.3)
	No CHD (N = 13)	10.0 (12.5)
Sex	Males (N = 43)	20.0 (10.0)
	Females (N = 10)	20.0 (19.4)

The small number of smokers in the sample limits the interpretation of interactions between PROP taster status, presence or absence of CHD, and sex on number of cigarettes smoked per day. Nine out of twelve cells had a N of five or less (Table 5.20), making interpretation and generalisations to a wider population inappropriate.

TABLE 5.20
MEDIAN ESTIMATED NUMBER OF CIGARETTES SMOKED PER WEEK, ACCORDING TO PROP TASTER STATUS, PRESENCE OR ABSENCE OF CHD, AND SEX - CELL MEDIANS

CHD	Sex	PROP Taster Status	N	Median no. of Cigarettes (Interquartile Range)
CHD	Male	Non-taster	15	20.0 (10.0)
		Medium taster	13	20.0 (5.0)
		Supertaster	4	20.0 (27.5)
	Female	Non-taster	1	20.0 (0.0)
		Medium taster	2	11.3 (0.0)
		Supertaster	5	20.0 (27.5)
No CHD	Male	Non-taster	6	10.0 (3.3)
		Medium taster	4	10.0 (15.3)
		Supertaster	1	20.0 (0.0)
	Female	Non-taster	2	15.0 (0.0)
		Medium taster	0	0.0 (0.0)
		Supertaster	0	0.0 (0.0)

5.4.11 Relationship between PROP Tasting and Age

There was no association between PROP acuity and age (r = -0.11, $p > 0.05$) in the whole sample, or among the women (r = 0.12, $p > 0.05$), but there was a small but significant correlation when the males were isolated (r = -0.18, $p < 0.05$).

There were no significant correlations between PROP acuity ratings and age for groups with (r = -0.15, $p > 0.05$) and without CHD (r = -0.08, $p > 0.05$).

5.5 Discussion

5.5.1 PROP Tasting Ability as a Potential Genetic Marker for Diet-Related Disease

There was a significant interaction between the effects of coronary heart disease and sex on PROP ratings. There has been no published study of PROP tasting in individuals with heart disease and healthy controls. The few existing studies of cancers are the closest comparison, though the degree of diet-relatedness varies with different forms of cancer. Milunicová et al. (1969) reported similar rates of non-tasting in healthy men and men with pulmonary carcinoma and prostate cancer, and lower (but not significantly different) rates of non-tasting (i.e. increased PTC acuity) in males with carcinomas of the thyroid and digestive tract. The present finding for the small sub-sample of females that CHD is associated with greater PROP acuity is consistent with Milunicová et al.'s result that female tasters were more susceptible to tumours of thyroid gland, breast, uterus, cervix, and ovary than non-tasters. However, it contrasts with Ahuja et al.'s (1977) report of a lower frequency of PTC tasting in patients with cervical cancer than healthy controls, and Drewnowski et al.'s (1999a, 2000) finding that women with breast cancer and those diagnosed as cancer free had similar responses to PROP.

The present exploratory study provides evidence that genetically mediated taste sensitivity to PROP could indeed operate as a genetic marker for CHD. Further study is needed to determine whether the finding that CHD is associated with decreased PROP tasting ability in men can be replicated, and to obtain more data for women. CHD was selected as an example of a diet-related disease, and there is potential for study of whether PROP tasting operates as a genetic taste marker for other diet-related conditions such as some cancers (e.g. bowel cancer), stroke, and hypertension.

The present sample were those who survived myocardial infarction or who had angina, those who died from a heart attack are not represented. Those who died could differ from those who survived in their PROP tasting ability, and liking/disliking of foods, alcoholic drinks and cigarettes, or had cardiovascular disease more acutely. A longitudinal approach could deal with this issue, and would allow differences between those survived and those who died from (the first) myocardial infarction to be compared.

5.5.2 Validity of Methodology used to Measure PROP Acuity

Drewnowski et al. (2001) recognised that measuring PROP detection thresholds and suprathreshold responses to solutions are not suitable for use in such large-scale epidemiological studies, and tested the validity of paper tests as an alternative. Such time consuming methods requiring one-on-one testing were also ruled out in the present study since potential participants were only accessible collectively in the community. PROP paper tests were chosen as they are quick to administer, making them suitable for testing large groups. Drewnowski tested whether generally observed relationships between PROP tasting and age, sex, and race using PROP solutions would be confirmed using PROP paper tests administered via post. Confirmation of previously observed patterns led them to conclude that use of PROP paper tests are indeed a valid measure of PROP perception and therefore are suitable for use as a screening tool for epidemiological studies.

5.5.3 Food Likes/Dislikes

As well as examining potential associations with diet-related disease, influences on food choice were also studied. Food likes/dislikes was used as a proxy measure of food choice rather than food intake, as liking/disliking may be determined by taste to a greater degree than food intake (Booth et al., 2001). Consistent with previous findings, women were more likely to list fruit among their three favourite foods than men. For example, Fraser et al. (2000) reported that men reported eating meat, eggs, milk, and sugary foods more frequently, and fruits and vegetables less frequently than women. As found previously, although not significant in the present study, non-tasters tended to be most likely, and supertasters least likely, to state having no food dislikes (Fischer et al., 1961; Fischer and Griffin, 1961; Glanville and Kaplan, 1965; Jefferson and Erdman, 1970; Drewnowski Henderson, Shore, and Barratt-Fornell, 1998). Similarly, participants with CHD were more likely (although not significantly) to report having no food dislikes than the control group without CHD. Supertasters and those with CHD were also most likely to list vegetables as a most disliked food (not significant). This is consistent with the hypothesis that individuals with heightened PROP perception are more likely to reject bitter tasting (and health promoting) vegetables, and thus be at increased risk of certain diet-related diseases.

5.5.4 Cigarettes and Alcohol

There were non-significant trends for non-tasters to be more likely to cite wine as their favourite alcoholic drink than supertasters. Wine is notably astringent tasting and thus expected to be more acceptable to non-tasters as they have a decreased tasting ability. Supertasters were more likely to list spirits and mixers as favourite alcoholic drink than medium tasters or supertasters. The taste of the alcohol is masked by the mixer, thus making it more palatable. Men were significantly more likely to cite lager/beer as a favourite alcoholic drink than women, and women more likely to cite wine as a favourite alcoholic drink than men. This may reflect conformity to sex roles rather than differences in taste perception. Men also reported drinking significantly more units of alcohol per week, and disliked the taste of cigarettes less, than women. These findings could be attributed to women's greater taste sensitivity or to social factors such as conformity to the social norms for their generation.

Different associations between PROP taster status and smoker/non-smoker status emerged for groups with and without CHD. There was a higher percentage of smokers among the non-tasters than supertasters among men and women without CHD as would be expected. Non-tasters are expected to be more likely to be smokers than medium tasters and supertasters since they are less sensitive to nicotine and the other bitter tasting components in cigarettes. However, among men and women with CHD there was a higher percentage of smokers among the *supertasters* than among the non-tasters. The fact that the expected trend was found among the control group but not those with CHD suggests that any effect of taste may be hidden by more influential factors in the latter group. A mortality effect could explain the different patterns. Those who died from (a first) myocardial infarction were not represented and could have been non-tasters and smokers which would have upheld the expected trend among those with coronary heart disease.

5.5.5 Age and Sex

A large proportion of the current sample of older adults demonstrated low levels of PROP taste acuity. This is consistent with reports that sensitivity to bitter tastes diminishes with age (Bartoshuk et al., 1986; Cowart, 1989; Murphy and Gilmore, 1989). Women had higher PROP ratings than men, consistent with previous findings (Bartoshuk et al., 1994; Bartoshuk et al., 1996b; Whissell-Buechy, 1990), although the difference was not significantly different. Since women's greater sensitivity to bitter tastes than men may function to avoid ingestion of bitter tasting toxins during pregnancy (Duffy and Bartoshuk, 1996a), and there is evidence that PROP bitterness perception decreases after menopause (Prutkin et al., 2000), men and women would be expected to have more similar PROP perception in older age.

5.5.6 Summary/Conclusion

There is evidence here that PROP tasting may serve as a genetic marker for heart disease. Further population studies are necessary, but there are implications for health programmes that promote dietary change which currently fail to acknowledge taste barriers. There is also potential for the use of PROP taste tests as a screening tool to identify those at increased risk of developing CHD and possibly other diet-related diseases.

Chapter Six

Overall Discussion

6.1 Multiple Aetiology of Food Choice

It is widely recognised that many variables affect food choice, and the aim of this thesis was to investigate whether PROP tasting ability was an influential factor. There was relatively weak evidence from the large body of data collected that taste acuity for PROP had a direct influence on food choice. There is recent evidence that age, sex and food adventurousness and neophilia/neophobia mediate the relationship between PROP tasting and food preferences (Snyder et al., 2001; Ullrich and Tepper, 2001; Carter et al., 2000) so perhaps a multifactorial model identifying an interaction of factors may be more revealing.

This conclusion mirrors the fact that the aetiology of food choice is very complex, with numerous influences many of which are interrelated. As yet there is no definitive model of food selection. The nature of the relationships between aetiological factors remains unclear and which factors are most important is still contentious (Tepper et al., 1997). For example Rozin and Vollmecke (1986) reviewed the relevant literature and proposed that food choices are influenced by an interaction between economic, biological, cultural and psychological factors as well as availability.

Biological influences include: innate likes/dislikes to ensure adequate intake of macronutrients and avoidance of poisons; a mixture of neophilia and neophobia to encourage both intake of new nutritive foods and avoidance of toxic elements; predisposition to alter liking/disliking in response to the delayed consequence (e.g. illness or satiety). The first biological influence encompasses genetically mediated PROP acuity since naturally occurring poisons often taste bitter. Their bitter taste may lead PROP tasters to avoid eating these plants and thus avoid their harmful effects. However, Rozin and Vollmecke (1986) state that very little of the variation in food likes and dislikes within a culture can be attributed to genetically based differences in taste perception. Culture has an enormous impact on food choice, and the authors go as far as to claim that if only one question could be asked in trying to find out as much as possible about an individual's food choices it would be "What is your culture or ethnic group?" Culture influences what foods are experienced, their flavouring and preparation and the social qualities associated with a food which make it desirable/undesirable. The impact of culture on food choice may lead to variation in reports of the relationship between PROP acuity and food choice between countries. It is pertinent to note here that the vast majority of PROP studies have been conducted with American samples, and there is no published research on PROP tasting and food choice with British samples to compare the present findings with. Psychological factors are responsible for variations in food likes/dislikes and intake within a culture. These are numerous, but include influence of other respected individuals, conditioning, context in which the food is presented, health beliefs and concern with weight (Drewnowski, 1990b).

An appreciation of the multiple aetiology of food choice led to the inclusion of a dietary restraint measure in Chapters Three and Four, especially since these studies were conducted with females. High levels of dietary restraint were associated with decreased reported intake of high fat foods and increased reported consumption of reduced calorie/low fat foods. Similar patterns were found when examining reported hedonic ratings, with restrained eaters liking the low calorie/fat foods such as vegetable and low fat cheese more than unrestrained eaters, and liking full fat milk less. These effects of dietary restraint could have negated any potential influence of PROP acuity.

Comparable findings were identified when examining the relationship between PROP tasting and body mass index. Both studies of food intake and food likes (Chapters Three and Four) found that dietary restraint had a significant effect on body mass index with restrained eaters having higher BMIs than unrestrained eaters. Although non-tasters had the highest BMI and supertasters the lowest, these trends were not significant.

6.2 Evidence for PROP Effects among Men but not Women

The studies in Chapter Three and Four found no effects of genetically mediated taste acuity for PROP on either food intake or food liking. However the study reported in Chapter Five suggested that PROP acuity could function as a genetic marker for heart disease and potentially other diet-related conditions. This can be explained by the fact that the former studies were conducted with women, where dietary restraint was found to influence food choices, and the latter finding was for men. These findings also support the conclusion that PROP taster status may interact with other factors to influence food choices.

Men tend be have lower dietary restraint scores than women (Klesges et al., 1992) which may lead their food choices to be influenced more by other factors such as taste. Males attributed taste as the most important factor influencing their choices, whereas females gave equal importance to health reasons and taste (Steptoe et al., 1995). When it comes to food rejection, men are most likely to reject foods due to taste factors, whereas females reject foods primarily for weight concerns, with taste coming a poor fourth to health and ethical reasons (Mooney and Walbourn, 2001). Since taste was not the main reason for food rejections, women may actually like the foods that they avoid.

Reports of PROP effects on BMI for men but not women (Tepper, 1998; Tepper and Ullrich, unpublished data, reported in Tepper, 1998) also suggest that different PROP effects on food choices may be seen in men and women. Most studies of food likes/dislikes have studied all female samples (e.g. Drewnowski, Henderson and Shore, 1997a, 1997b; Drewnowski, Henderson, Shore, and Barratt-Fornell, 1997; Drewnowski, Henderson, and Barratt-Fornell, 1998; Drewnowski et al., 1999b; Ly and Drewnowski, 2001; Akella et al., 1997; Jerzsa-Latta et al., 1990; Kaminski et al., 2000; Lucchina et al., 1995) or predominantly female samples (e.g. Bartoshuk et al., 1998; Duffy et al., 1996), and information is lacking on PROP effects on men's dietary intakes and hedonic responses, among whom relationships may be more likely to been identified. Sex influenced food choices of the older adults in Chapter Five with women liking fruit more than men. Women also liked beer/lager less and drank less alcohol than men. Snyder et al. (2001) found that PROP perception influenced food likings by interacting with age and sex, and concluded that these effects may impact diet-mediated cardiovascular or cancer risk.

6.3 PROP Acuity and Age

In Chapter Five, an investigation of PROP tasting ability as a potential genetic marker for diet-related disease, bitter taste acuity decreased slightly with increasing age among men, but not among women or men and women combined. However this association did not occur in the participants studied in Chapters Three and Four when investigating PROP effects on food choice. Older adults were sampled in Chapter Five (49 - 82 years, mean age: 66.3) compared to Chapter Three (18 - 45 years, mean age: 21.5) and Chapter Four (18 - 42 years, mean age: 22.1 years). Other studies which studied a wide age range also found that taste sensitivity to PTC decreased with increasing age (Harris and Kalmus, 1949: 10-91 years; Whissell-Buechy, 1990: 4-79 years). However, Reed et al. (1995) and Niewind et al. (1988) reported that PROP and PTC tasting ability was independent of age, although full ranges of older adults were not sampled (Reed et al.: 18-62 years; Niewind et al.: 55-70 years).

6.4 Methodological Issues

6.4.1 Food Diaries and Hedonic Ratings Based on Tasting versus Food Frequency and Food Preference Questionnaires

Food diaries and hedonic responses to actual foods were used as the primary measures of food intake and food liking rather than food frequency and food preference questionnaires as they were thought to have more validity. Food frequency questionnaires provide only a subjective estimate of usual intake and both questionnaires tend to measure attitudes to food names (Drewnowski and Rock, 1995). Food frequency and food preference questionnaires were also used in this thesis to determine whether the results would be different to those found using food diaries and hedonic responses to tasted foods.

When examining the relationship between PROP tasting ability and food likes, the results produced by both measures of liking/disliking were very similar. However there was one instance where results differed. When taste responses to real foods were studied, there was an effect of dietary restraint on liking of vegetables, but not on the cheeses, milks or fruit juices. However when a food preference questionnaire was used, dietary restraint was found to influence hedonic ratings of different foods, namely cheeses and milks, and vegetables only approached significance. This suggests that responses to both measures of liking do differ although there was no clear indication that one measure is better than the other.

The different nature of the data yielded by the food diaries and food frequency questionnaires made them more difficult to compare directly. However both produced the same overall conclusion: there is not a clear relationship between PROP acuity and food intake. Overall comparison of the questionnaire methods with the food diaries and likes/dislikes based on actual tasting therefore suggests that results are generally consistent, although it is still believed that the latter methods are more revealing.

6.4.2 Recent Innovations in Determining PROP Taster Status

Previous research showed that sodium chloride and tones were equally good standards (Marks et al., 1988), i.e. neither the saltiness of NaCl nor the loudness of tones appeared to be associated with the taste of PROP. However it was later discovered that context effects influenced this finding (Bartoshuk, 2000a; Bartoshuk, 2000b). Context effects occur when "an intense stimulus in one modality can intensify sensations from another modality" (Duffy and Bartoshuk, 2000, p.648). For example, if a taster perceives an intense taste from PROP, he/she will rate the subsequent tone as louder than a non-taster. This obscures the perceptual difference between PROP and the other modality and between PROP taster groups. When context effects are eliminated (by presenting PROP last, or in another session), the use of tones as a standard reveals the largest differences between taster groups (Bartoshuk et al., 1998). It is therefore possible, that repetition of the present work with a tone standard could increase the magnitude of any PROP taster status effect. Bartoshuk and her co-workers stated that although the use of a NaCl standard is more conservative it is still useful (Bartoshuk et al., 1999a). They also noted that a PROP/NaCl ratio "works well" for classifying taster groups because the ratio varies considerably from non-tasters to supertasters, and that it is also more practical to use.

The issue of an appropriate standard is also relevant to the Labelled Magnitude Scale, a modified version of which (the General Labelled Magnitude Scale; gLMS) was used in place of magnitude estimation in the last study (Green et al., 1993). The label at the top of the LMS "strongest imaginable" (in reference to oral sensations) was used as a standard as it was thought to represent equivalent perceptual intensity across all individuals (Borg, 1982). Linda Bartoshuk challenged this assumption (Bartoshuk, 2000a; Bartoshuk, 2000b). She and her colleagues demonstrated that "strongest imaginable" oral sensations are not equivalent across non-tasters, medium tasters, and supertasters (Bartoshuk et al., 2000a; Bartoshuk et al., 2000b). Supertasters rated oral burn (e.g. capsaicin burn; correlates with PROP bitterness) as more intense than oral pain (e.g. toothache; does not correlate with PROP bitterness), whereas non-tasters rated oral pain highest. When "strongest imaginable sensation of any kind" was the top label, PROP effects were found that were equivalent with those found using magnitude matching using sound as a standard. This was not found when the original label was used. The timing of this recent innovation allowed it to be incorporated into the last study, and was particularly useful since the nature of the population made it necessary to use a time-efficient method that could be easily administered outside of the laboratory in a community setting.

6.5 Applications/Implications of Thesis Findings.

The current research was initiated with the hope of being able to provide information that could contribute to the effectiveness of health programmes promoting dietary change. An understanding of the determinants of food selection is necessary before designing and implementing strategies to change these behaviours. In seeking to promote healthy eating, the ultimate potential application of the research in this thesis was to provide further insight into the aetiology of diet-related disease. Finding preliminary evidence for a genetic taste marker for coronary heart disease has implications for developing a screening tool to identify those most at risk of CHD and potentially other diet-related diseases.

6.6 Future Directions

Since males report that taste is more important in their food choices/rejection than females (Steptoe et al., 1995; Mooney and Walbourn, 2001), genetically-mediated PROP tasting ability may be more likely to influence males' foods rejections and food choices than females'. More research on the effect of PROP tasting on food choice among men is needed since most work has tended to focus on women. Men might also be more at risk from diet-related disease given that they report eating meat, eggs, milk, and sugary foods more frequently, and fruits and vegetables less frequently than women (Fraser et al., 2000). Sex is just one of the multiple factors which influence food choice, and future research would benefit from looking at the interaction between the effects of PROP tasting and other determinants. Present work tends to be quantitative in nature, but given the complex nature of food choice, a more individualised qualitative approach using interviews may be more revealing than categorising people into a small number of large groups. This would allow detailed focus on what and why people like and select particular foods, and to look at factors such as social context, and individual perceptions of what is a "healthy" or a "fatty" food. This would enable comparing and contrasting of commonalities within and between taster groups.

The PROP literature has progressed from looking at the associations between PROP tasting ability and taste acuity for laboratory preparations (e.g. Bartoshuk, 1979; Gent and Bartoshuk, 1983; Hall et al., 1975), to the more applied perspective of food likes/dislikes and food intake (e.g. Fischer et al., 1961; Glanville and Kaplan, 1965a; Anliker et al., 1991; Duffy et al., 2001; Ly and Drewnowski, 2001), although there still tends to be reliance on questionnaire methods rather than actual sensory responses and food records. While there is still an opportunity to investigate PROP tasting and taste acuity and food choice, the next logical step is to progress to investigating diet-related disease. This area is still very much in its infancy, and needs considerably more research attention. Large population studies are needed, including a longitudinal approach, and the full range of diet-related conditions suitable for study. Recent advances in the psychophysical methodology of measuring taste acuity for PROP, led by Linda Bartoshuk, means that future measurements will be more rigorous, and the literature has yet to benefit fully from them.

6.7 Summary/Conclusion

There was no substantial evidence that genetically mediated taste acuity for PROP had a direct influence on food likes/dislikes or intake. Investigation of PROP tasting among individuals with Coronary Heart Disease and a control group, suggested that PROP acuity could function as a genetic taste marker for heart disease and potentially other diet-related conditions. CHD was associated with decreased PROP acuity among men.

This is consistent with the findings that decreased PROP acuity tended to be associated with increased likelihood to be a smoker and higher body mass index. It is concluded that there is not a simple and direct relationship between PROP tasting ability and food choice. An interaction between PROP acuity and other mediating factors may be involved in a more complex model. The evidence that PROP taste acuity may function as a genetic taste marker for coronary heart disease has wide implications for understanding the aetiology, and ultimately the prevention, of diet-related disease.

REFERENCES

ADLER, E., HOON, M.A., MUELLER, K.L., CHANDRASHEKAR, J., RYBA, N.J.P., and ZUKER, C.S. (2000). A novel family of mammalian taste receptors. Cell, 100, 693-702.

AHUJA, Y.R., REDDY, O.S., and REDDY, S.S. (1977). PTC taste-sensitivity among women with carcinoma of the cervix. Anthropology, 24, 40-42.

AKELLA, G.D., HENDERSON, S.A., and DREWNOWSKI, A. (1997). Sensory acceptance of Japanese green tea and soy products is linked genetic sensitivity to 6-n-propylthiouracil. Nutrition and Cancer, 29 (2), 146-151.

AKESSON, H.O. (1959). Taste deficiency for phenyl-thio-urea in southern Sweden. Acta Geneticae, Medicae et Gemellologiae, 8, 431-433.

ANLIKER, J., BARTOSHUK, L., FERRIS, A.M., and HOOKS, L.D. (1991). Children's food preferences and genetic sensitivity to the bitter taste of 6-n-propylthiouracil (PROP). American Journal of Clinical Nutrition, 54, 316-320.

BARTOSHUK, L.M. (1978). The psychophysics of taste. The American Journal of Clinical Nutrition, 31,1068-1077.

BARTOSHUK, L.M. (1979). Bitter taste of saccharin related to the genetic ability to taste the bitter substance 6-n-propylthiouracil. Science, 205, 934-935.

BARTOSHUK, L. (1980). Influence of chemoreception and psychologic state on food selection. International Journal of Obesity, 4, 351-355.

BARTOSHUK, L.M. (1990). Chemosensory alterations and cancer therapies. NCI Monographs, 9, 179-184.

BARTOSHUK, L.M. (1993). The biological basis of food perception and acceptance. Food Quality and Preference, 4, 21-32.

BARTOSHUK, L.M. (2000a). Psychophysical advances aid the study of genetic variation in taste. Appetite, 34, 105.

BARTOSHUK, L.M. (2000b). Comparing sensory experiences across individuals: Recent psychophysical advances illuminate genetic variation in taste perception. Chemical Senses, 25, 447-460.

BARTOSHUK, L.M., CASERIA, D., CATALANOTTO, F., DABRILA, G., DUFFY, V.B., LUCCHINA, L.A., NADOOLMAN, W., SASAKI, C., SNYDER, D.J., and WOLFE, J. (1996a). Do taste-trigeminal interactions play a role in oral pain? Chemical Senses, 21, 578.

BARTOSHUK, L.M., CONNER, E., GRUBIN, D., KARRER, T., PALSCO, M., SNOW, D., PELCHAT, M., and DANOWSKI, S. (1993). PROP supertasters and the perception of ethyl alcohol. Chemical Senses, 18, 526-527.

BARTOSHUK, L.M., CUNNINGHAM, K.E., DABRILA, G.M., DUFFY, V.B., ETTER, L., FAST, K.R., LUCCHINA, L.A., PRUTKIN, J.M., and SNYDER, D.J. (1999a). From sweets to hot peppers: Genetic variation in taste, oral pain, and oral touch. G.A. BELL and A.J. WATSON (Eds.), Tastes and Aromas: The Chemical Senses in Science and Industry. Sydney: UNSW Press.

BARTOSHUK, L. M., DUFFY, V.B., ETTER, L., FAST, K., GARVIN, V., LUCCHINA, L.A., RODIN, J., SNYDER, D.J., STRIEGEL-MOORE, R., and WOLF, H. (1997). Variability in taste, oral pain, and taste anatomy: Evidence for menstrual control over oral perception. Appetite, 33, 228-229.

BARTOSHUK, L. M., DUFFY, V.B., FAST, K., GREEN, B., KVETON, J., LUCCHINA, L.A., PRUTKIN, J., SNYDER, D.J., and TIE, K. (1999b). Sensory variability, food preferences and BMI in non-, medium and supertasters of PROP. Appetite, 33, 228-229.

BARTOSHUK, L. M., DUFFY, V.B., FAST, K., GREEN, B.G., and PRUTKIN, J. (2000a). Invalid sensory comparisons across groups: Examples from PROP research. ISOT/ECRO, Brighton, 2000.

BARTOSHUK, L. M., DUFFY, V.B., FAST, K., GREEN, B.G., and SNYDER, D.J. (2001). The General Labeled Magnitude Scale provides valid measures of genetic variation in taste and may be a universal psychophysical ruler. Philadelphia, SSIB, 2001.

BARTOSHUK, L. M., DUFFY, V.B., LUCCHINA, L.A., PRUTKIN, J., and FAST, K. (1998). PROP (6-n-propylthiouracil) supertasters and the saltiness of NaCl. Annals of the New York Academy of Sciences, 855, 793-796.

BARTOSHUK, L. M., DUFFY, V.B., and MILLER, I. J. (1994). PTC/PROP tasting: anatomy, psychophysics, and sex effects. Physiology and Behavior, 56(6), 1165 –1171.

BARTOSHUK, L.M., DUFFY, V.B., REED, D., and WILLIAMS, A. (1996b). Supertasting, earaches and head injury: genetics and pathology alter our taste worlds. Neuroscience and Biobehavioral Reviews, 20(1), 79-87.

BARTOSHUK, L.M., FAST, K., GREEN, B.G., PRUTKIN, J.M., SNYDER, D.J., and GREEN, B.G. (2000b). Magnitude matching and a modified LMS produce valid sensory comparisons for PROP studies. Appetite, 35, 277.

BARTOSHUK, L.M., FAST, K., KARRER, T.A., MARINO, S., PRICE, R.A., and REED, D.A. (1992). PROP supertasters and the perception of sweetness and bitterness. Chemical Senses, 17, 594.

BARTOSHUK, L.M., RENNERT, J., RODIN, J., and STEVENS, J.C. (1982). Effects of temperature on the perceived sweetness of sucrose. Physiology and Behavior, 28, 905-910.

BARTOSHUK, L.M., RIFKIN, B., MARKS, L.E., and BARS, P. (1986). Taste and Aging. Journal of Gerontology, 41, 51-57.

BARTOSHUK, L.M., RIFKIN, B., MARKS, L.E., and HOOPER, J.E. (1988). Bitterness of KCl and benzoate: related to genetic status for sensitivity to PTC/PROP. Chemical Senses, 13, 517-528.

BAUER, D. and UTERMOHLEN, V. (1999). Perception of general food tastiness is related to the ability to taste 6-n-propylthiouracil (PROP). Appetite, 33, 235.

BEIDLER, L.M. and SMITH, J.C. (1991). Effects of radiation therapy and drugs on cell turnover and taste. T.V.GETCHELL (Ed.). Smell and Taste in Health and Disease. New York: Raven Press.

BEIGUELMAN, B. (1964). Taste sensitivity to phenylthiourea and menstruation. Acta Geneticae, Medicae et Gemellologiae, 13, 197-199.

BHATIA, S. and PURI, R. (1991). Taste sensitivity in pregnancy. Indian Journal of Physiology and Pharmacology, 35, 121-124.

BHATIA, S., SICAR, S.S., and GHORAI, B.K. (1990). Gustatory differences in hypothyroid and hyperthyroid tasters and nontasters. Indian Journal of Physiology and Pharmacology, 34, 201-205.

BINGHAM, S.A., CASSIDY, A., OLE, T.J., WELCH, A., RUNSWICK, S.A., BLACK, A.E., THURNHAM, D., BATES, C., KHAW, K.T., and KEY, T.J. (1995). Validation OF weighed records and other methods of dietary assessment using the 24-h urine nitrogen technique and other biological markers. British Journal of Nutrition, 73, 531-550.

BLAKESLEE, A.F. (1932). Genetics of sensory thresholds: taste for phenylthiocarbamide. National Academy of Sciences. Proceedings, 18, 120-130.

BLAKESLEE, A.F. and SALMON, M.R. (1931). Odor and taste blindness. Eugenical News, 16, 105-109.

BOOTH, S.L., SALLIS, J.F., RITENBAUGH, C., HILL, J.O., BIRCH, L.L., FRANK, L.D., GLANZ, K., HIMMELGREEN, D.A., MUDD, M., POPKIN, B.M., RICKARD, K.A., ST JEOR, S., and HAYS, N.P. (2001). Environmental and societal factors affect food choice and physical activity: rationale, influences, and leverage points. Nutritional Reviews, 59, S21-39.

BORECKI, I.B., RICE, T., PERUSSE, L., BOUCHARD, C. and RAO, D.C. (1994). An exploratory investigation of genetic linkage with body composition and fatness phenotypes: the Quebec family study. Obesity Research, 2, 213-219.

BORG, G. (1982). A category scale with ratio properties for intermodal and interindividual comparisons. H.G. GEISSSLER and P. PETXOLD (Eds.), Psychophysical Judgement and the Process of Perception. Berlin: VEB.

BOYD, W.C. and BOYD, L.G. (1937-8). Sexual and racial variations in the ability to taste phenyl-thio-carbamide, with some data on inheritance. Annals of Eugenics, 8, 46-51.

CARTER, E., DONLEY, V., SONSON, C., SANTANIELLO, N., STALEY, M., and RAUDENBUSH, B. (2000). PTC sensitivity differentiates food neophobics and food neophilics. Appetite, 35, 280.

CHAUTARD-FRIERE-MAIA, E.A. (1974). Linkage relationships between 22 autosomal markers. Annals of Human Genetics, 38, 191-198.

COHEN, D., BARTOSHUK, L.M., FAST, K., and DUFFY, V.B. (1999). Fungiform papillae anatomy: variation with sex, genetic taste variation, and pathology. Chemical Senses, 24, 604.

CONNEALLY, P.M., DUMONT-DRISCOLL, M., HUNTZINGER, R.S., NANCE, W.E., and JACKSON, C.E., (1976). Linkage relations of the Loci for Kell and phenylthiocarbamide taste sensitivity. Human Heredity, 26, 267-271.

CONTENTO, I.R., MICHELA, J.L., and Williams, S.S. (1995). Adolescent food choice criteria: role of weight and dieting status. _Appetite_, 25, 51-76.

CORNSWEET, T.N. (1962). The staircase method in psychophysics. _American Journal of Psychology_, 75, 485-491.

COWART, B.J. (1989). Relationships between taste and smell across the adult life span. C. MURPHY, W.S. CAIN, and D.M. HEGSTED (Eds.), _Nutrition and the Chemical Senses in Aging: Recent Advances and Current Research Needs_. New York: The New York Academy of Sciences.

CUBERO-CASTILLO, E.M. and NOBLE, A.C. (2000). The effect of compound specific sensitivity and carry-over effects on bitterness perception. _Chemical Senses_, 25, 640.

CUNHA, A.X. and ABREU, M.D.A. (1956). A sensibilidade gustative da feniltiocarbamida em Portugueses. _Contribuicao Est Antropologia Portugues_, 6, 85.

DABRILA, G.M., BARTOSHUK, L.M., and DUFFY, V.B. (1995). Preliminary findings of genetic taste status association with fat intake and body mass index in adult females. _Journal of the American Dietetic Association_, A41.

DAS, S.R. (1956). A contribution to the heredity of the PTC taste character based on a study of 845 sib-pairs. _Annals of Human Genetics_, 20, 334-343.

DAS, S.R. (1958). Inheritance of the PTC taste character in man: An analysis of 126 Rarhi Brahmin families of west Bengal. _Annals of Human Genetics_, 22, 200-212.

DE CASTRO, J.M. (1995). The relationship of cognitive restraint to spontaneous food and fluid intake of free-living humans. _Physiology and Behavior_, 52, 287-295.

DICARLO, S.T. and POWERS, A.S. (1998). Propylthiouracil tasting as a possible genetic association marker for two types of alcoholism. _Physiology and Behavior_, 64(2), 147-152.

DEPARTMENT OF HEALTH. (1992). The Health of the Nation: A Strategy for Health in England. London: HMSO.

DEPARTMENT OF HEALTH. (1994). Nutritional aspects of cardiovascular disease. Report on health and social subjects 46. London: HMSO.

DEPARTMENT OF HEALTH. (1998). Our Healthier Nation: A Contract for Health. London: HMSO.

DEPARTMENT OF HEALTH. (2000a). The NHS Cancer Plan: A Plan for Investment, A Plan for Reform. London: HMSO.

DEPARTMENT OF HEALTH. (2000b). The National School Fruit Scheme. London: HMSO.

DEPARTMENT OF HEALTH AND HUMAN SERVICES (2000). Healthy People 2010: Understanding and Improving Health. Washington, DC: US Government Printing Office.

DREWNOWSKI, A. (1987). Sweetness and obesity. J. DOBBING (Ed.), Sweetness. Berlin: Springer.

DREWNOWSKI, A. (1990a). Dietary fats: perceptions and preferences. Journal of the American College of Nutrition, 431-435.

DREWNOWSKI, A. (1990b). Genetics of taste and smell. A.P. SIMOPOULOS, and B. CHILDS (Eds.), World Review of Nutrition and Dietetics, 63, 194-208.

DREWNOWSKI, A., and GOMEZ-CARNEROS, C. (2000). Bitter taste, phytonutrients, and the consumer: a review. American Journal of Clinical Nutrition, 72, 1424-1435.

DREWNOWSKI, A. and HANN, C. (1999). Food preferences and reported frequencies of food consumption as predictors of current diet in young women. American Journal of Clinical Nutrition, 70, 28-36.

DREWNOWSKI, A., HENDERSON, S.A., and BARRATT-FORNELL, A. (1998). Genetic sensitivity to 6-n-propylthiouracil and sensory responses to sugar and fat mixtures. Physiology and Behavior, 63(5), 771-777.

DREWNOWSKI, A., HENDERSON, S.A., and BARRATT-FORNELL, A. (2001). Genetic taste markers and food preference. Drug Metabolism and Disposition, 29, 535-538.

DREWNOWSKI, A., HENDERSON, S., HANN, C.S., BARRATT-FORNELL, A., and RUFFIN, M. (1999a). Age and food preferences influence dietary intakes of breast care patients. Health Psychology, 18, 570-578.

DREWNOWSKI, A., HENDERSON, S.A., HANN, C.S., BERG, W.A., and RUFFIN, M.T. (2000). Genetic taste markers and preferences for vegetables and fruit of female breast care patients. Journal of the American Dietetic Association, 100, 191-197.

DREWNOWSKI, A., HENDERSON, S.A., LEVINE, A., and HANN, C. (1999b). Taste and food preferences as predictors of dietary practices in young women. Public Health Nutrition, 2, 513-519.

DREWNOWSKI, A., HENDERSON, S., and SHORE A.B. (1997a). Taste responses to naringin, a flavanoid, and the acceptance of grapefruit juice are related to genetic sensitivity to 6-n-propylthiouracil. American Journal of Clinical Nutrition, 66, 391-397.

DREWNOWSKI, A., HENDERSON, S.A., and SHORE, A.B., (1997b). Genetic sensitivity to 6-n-propylthiouracil (PROP) and hedonic responses to bitter and sweet tastes. Chemical Senses, 22, 27-37.

DREWNOWSKI, A., HENDERSON, S.A., SHORE, A.B., and BARRATT-FORNELL, A. (1997). Nontasters, tasters, and supertasters of 6-n-propylthiouracil (PROP) and hedonic response to sweet. Physiology and Behavior, 62(3), 649-655.

DREWNOWSKI, A., HENDERSON, S.A., SHORE, A.B., and BARRATT-FORNELL, A. (1998). Sensory responses to 6-n-propylthiouracil (PROP) or sucrose solutions and food preferences in young women. Annals of the New York Academy of Sciences, 855, 797-801.

DREWNOWSKI, A., KRISTAL, A., and COHEN, J. (2001). Genetic taste responses to 6-n-propylthiouracil among adults: a screening tool for epidemiological studies. Chemical Senses, 26, 483-489.

DREWNOWSKI, A. and ROCK, C.L. (1995). The influence of genetic taste markers on food acceptance. American Journal of Clinical Nutrition, 62(3), 506-511.

DREWNOWSKI, A. and SCHWARTZ, M., (1990). Invisible fats: sensory assessment of sugar/fat mixtures. Appetite, 14, 203-217.

DUFFY, V.B. and BARTOSHUK, L.M. (1996a). Sensory factors in feeding. E. CAPALDI (Ed.), Why We Eat What We Eat: The Psychology of Eating. Washington DC, American Psychological Association.

DUFFY, V.B. and BARTOSHUK, L.M. (1996b). Genetic taste perception and food preferences. Food Quality and Preference, 7, 309.

DUFFY, V.B. and BARTOSHUK, L.M. (2000). Food acceptance and genetic variation in taste. Journal of the American Dietetic Association, 100, 647-655.

DUFFY, V.B., BARTOSHUK, L.M., LUCCHINA, L.A., SNYDER, D.J., and TYM, A. (1996). Supertasters of PROP (6-n-propylthiouracil) rate the highest creaminess to high-fat milk products. Chemical Senses, 22, 598.

DUFFY, V.B., BARTOSHUK, L.M., STRIEGEL-MOORE, R., and RODIN, J. (1998). Taste changes across pregnancy. Annals of the New York Academy of Sciences, 855, 805-809.

DUFFY, V.B., BARTOSHUK, L.M., and WEINGARTEN, H.P. (1995). PROP (6-n-propylthiouracil) Supertasters: sex and sweet preference. Appetite, 24, 186.

DUFFY, V.B., FAST, K., COHEN, Z., CHODOS, E., and BARTOSHUK, L.M. (1999). Genetic taste status associates with fat food acceptance and body mass index in adults. Chemical Senses, 24, 545-546.

DUFFY, V.B. and PETERSON, J.M. (2000). Genetic variation in taste: associations with alcohol sensation and intake. Chemical Senses, 25, 638.

DUFFY, V.B. PHILLIPS, M.N., PETERSON, J.M., and BARTOSHUK, L.M. (2001). Bitterness of 6-n-propylthiouracil (PROP) associates with bitter sensations and intake of vegetables. Philadelphia, SSIB, 2001.

DUFFY, V.B., WEINGARTEN, H.P., and BARTOSHUK, L.M. (1995). Preference for sweet and fat foods in young adults associated with PROP (6-n-propylthiouracil) genetic taste status and sex. Chemical Senses, 20(6), 688.

ELLERD, M. A. (1998). Inheritance of the polymorphic ability to taste PTC. American Journal of Human Biology, 10, 122.

ELLERD, M. A. (1999). Genotype X sex (G X S) interactions in the polymorphic ability to taste phenylthiocarbamide (PTC). American Journal of Human Biology, 11, 110.

ETTER, L. (1999). Variation in taste perception across the menstrual cycle. MD Thesis, Yale University.

FALCONER, D.S. (1947). Sensory thresholds for solutions of phenylthiocarbamide. Annals of Eugenics, 13, 211-222.

FERNBERGER, S.W. (1932). A preliminary study of taste deficiency. American Journal of Psychology, 44, 322-326.

FISCHER, R. (1971). Gustatory, behavioral and pharmacological manifestations of chemoreception in man. G.OHLOFF, and A.F. THOMAS (Eds.), Gustation and Olfaction. London: Academic Press.

FISCHER, R. and GRIFFIN, F. (1961). Quinine dimorphism among "non-tasters" of 6-n-propylthiouracil. Experientia, 17, 36-38

FISCHER, R., and GRIFFIN, F. (1964). Pharmacogenic aspects of gustation. Drug Research, 14, 673-686.

FISCHER, R., GRIFFIN, F., ENGLAND, S., and GARN, S.M. (1961). Taste thresholds and food dislikes. Nature, 191, 1328.

FISCHER, R., GRIFFIN, F., and KAPLAN, A.R. (1963). Taste thresholds, cigarette smoking, and food dislikes. Medicina Experimentalis, 9, 151-167.

FORRAI, G. and BANKOVI, G. (1984). Taste perception for phenylthiocarbamide and food choice: A Hungarian twin study. Acta Physiologica Hungarica, 64,33-40.

FOX, A.F. (1931). Six in ten "tasteblind" to bitter chemical. Science Newsletter, 9, 249.

FRANK, M.E., HETTINGER, T.P., and CLIVE, J.M. (1995). Current trends in measuring taste. R.L. DOTY (Ed.), Handbook of Olfaction and Gustation. New York: Marcel Dekker.

FRANK, R.A. and KORCHMAR, D.L. (1985). Gustatory processing differences in PTC tasters and nontasters: a reaction time analysis. Physiology and Behavior, 35, 239-242.

FRASER, G.E., WELCH, A., LUBEN, R., BINGHMA, S.A., and DAY, N.E. (2000). The effect of age, sex and education on food consumption of a middle-aged English cohort - EPIC in East Anglia. Preventative Medicine, 30, 26-34.

FREEMAN, R.P.J., FALAHEE, M.B., JOHNSON, R., and MADDEN, P.G. (2001). Taste sensitivity to 6-n-propylthiouracil (PROP): A possible genetic marker for liking for cigarettes. Chemical Senses, 26, 765.

FREIRE-MAIA, A. (1960). Smoking and P.T.C. taste sensitivity. Annals of Human Genetics, 24, 333-341.

FREIRE-MAIA, A. and QUELCE-SALGADO, A. (1960). Taste sensitivity to P.T.C. in samples from three Brazilian populations. Annals of Human Genetics, 24, 97-102.

FRENCH, S.A., JEFFERY, R.W., and WING, R.A. (1994). Food intake and physical activity: a comparison of three measures of dieting. Addictive Behaviors, 19, 401-409.

FURST, T., CONNORS, M., BISOGNI, C.A., SOBAL, J., and FALK, L.W. (1996). Food Choice: A conceptual model of process. Appetite, 26, 247-266.

GENT, J.F. and BARTOSHUK, L.M. (1983). Sweetness of sucrose neohesperidin dihydrochalcone, and saccharin is related to the genetic ability to taste the bitter substance 6-n-propylthiouracil, Chemical Senses, 7, 265-272.

GILBERTSON, T.A., FONTENOT, D.T., LIU, L., ZHANG, H., and MONROE, W.T. (1997). Fatty acid modulation of K^+ channels in taste receptor cells: gustatory clues for dietary fat. American Journal of Physiology - Cell Physiology, 41(4), 1203-1210.

GLANVILLE, E.V. and KAPLAN, A.R. (1965a). Food preference and sensitivity of taste for bitter compounds. Nature, 205, 251-253.

GLANVILLE, E.V. and KAPLAN, A.R. (1965b). The menstrual cycle and sensitivity of taste perception. The American Journal of Obstetrics and Gynecology, 92, 189- 194.

GOLDSMITH, M.C. and KANAREK, R.B. (2001). Genetically determined bitter perception influences human food preferences. Philadelphia, SSIB, 2001.

GREEN, B.G., DALTON, P., COWART, B., SHAFFER, G., RANKIN, K., and HIGGINS, J. (1996). Evaluating the "Labeled Magnitude Scale" for measuring sensations of taste and smell. Chemical Senses, 21, 323-334.

GREEN, B.G., SCHAFFER, G.S., and GILMORE, M.M. (1993). Derivation and evaluation of a semantic scale of oral sensation magnitude with apparent ratio properties. Chemical Senses, 18, 683-702.

GUO, S-W. and REED, D.R. (2001). The genetics of phenylthiocarbamide perception. Annals of Human Biology, 28, 111-142.

HALL, A.R. and BLAKESLEE, A.F. (1945). Effect of smoking on taste thresholds for phenyl-thio-carbamide (PTC). Proceedings of the National Academy of Sciences of the Unites States of America, 31, 390.

HALL, M.J., BARTOSHUK, L.M., CAIN, W.S., and STEVENS, J.C. (1975). PTC taste blindness and the taste of caffeine. Nature, 253, 442-443.

HARRIS, H. and KALMUS, H. (1949). The measurement of taste sensitivity to phenylthiourea (PTC). Annals of Eugenics, 15, 24-31.

HARRIS, H. and KALMUS, H. (1951). The distribution of taste thresholds for phenylthiourea of 384 sib pairs. Annals of Eugenics, 226-230.

HARTMAN, G. (1939). Application of individual taste difference towards phenyl-thio-carbamide in genetic investigations. Annals of Eugenics, 9, 123-135.

HESSELBROCK, V.M., STABENAU, J.R., HESSELBROCK, M.N., MEYER, R.E., and BABOR, T.F. (1982). The nature of alcoholism in patients with different family histories for alcoholism. Progress in Neuropsychopharmacology and Biological Psychiatry, 6, 607-614.

HETZEL, B.S. (1993). The control of iodine deficiency. American Journal of Public Health, 83(4), 494-495.

HUGHES, J. (2000). The Case for Increasing the Population Consumption of Fruit and Vegetables and the Evidence for the Effectiveness of Interventions. Paper prepared for the Department of Health. Unpublished.

HUTCHINSON, I., SEGOVIA, C., LAING, D.G., and JINKS, A. (2001). Fungiform papillae - Differences between children and adults. Chemical Senses, 26, 721.

INTRANUOVO, L.R. and POWERS, A.S. (1998). The perceived bitterness of beer and 6-n-propylthiouracil (PROP) taste sensitivity. Annals of the New York Academy of Sciences, 855, 813-815.

JEFFERSON, S.C. and ERDMAN, A.M. (1970). Taste sensitivity and food aversions of teenagers. Journal of Home Economics, 62(8), 605-608.

JERZSA-LATTA, M., KRONDL, M., and COLEMAN, P. (1990). Use and perceived attributes of cruciferous vegetables in terms of genetically-mediated taste sensitivity. Appetite, 15, 127-134.

KAJIURA, H., SHIMAMOTO, K., and YOKOMUKAI, Y. (1997). The effect of ethanol and iso-alpha-acids on taste. Chemical Senses, 713.

KALMUS, H. (1958). Improvements in the classification of taster genotypes. Annals of Human Genetics, 222-230.

KALMUS, H. (1962). Genetical taste polymorphism and thyroid disease. Proceedings of the 2nd International Conference of Human Genetics, Rome.

KALMUS, H. (1971). Genetics of taste. L.M. BEIDER (Ed.), Handbook of Sensory Physiology: Chemical Senses 2. Berlin: Springer-Verlag.

KALMUS, H. and FARNSWORTH, D. (1959). Impairment and recovery of taste following irradiation of the oropharynx. Journal of Laryngology and Otology, 73, 180-182.

KAMINSKI, L.C., HENDERSON, S.A., and DREWNOWSKI, A. (2000). Young women's food preferences and taste responsiveness to 6-n-propylthiourail (PROP). Physiology and Behavior, 68, 691-697.

KAPLAN, A., FISCHER, R., KARRAS, A., GRIFFIN, F., POWER, W., MARSTERS, R., and GLANVILLE, E. (1967). Taste thresholds in twins and siblings. Acta Geneticae, Medicae et Gemellologiae, 16, 229-243.

KAPLAN, A.R., GLANVILLE, E.V., and FISCHER, R. (1964). Taste thresholds for bitterness and cigarette smoking. Nature, 202, 1366.

KARRER, T. and BARTOSHUK, L. (1991). Capsaicin desensitization and recovery on the human tongue. Physiology and Behavior, 49, 757-764.

KARRER, T., BARTOSHUK, L.M., CONNER, E., FEHERENBAKER, S., GRUBIN, D., and SNOW, D. (1992). PROP status and its relationship to the perceived burn intensity of capsaicin at different tongue loci. Chemical Senses, 17, 649.

KELLER, K.L., STEINMANN, L., NURSE, R.J., and TEPPER, B.J. (1999). Genetic sensitivity to 6-n-propylthiouracil (PROP) influences food preferences in preschool children. 22. Human taste psychophysics. Chemical Senses, 24, 546.

KLEM, M.L., KLESES, R.C, BENE, C.R., and MELLON, M.W. (1990). A psychometric study of restraint: The impact of race, gender, weight and marital status. Addictive Behaviors, 15, 147-152.

KLESGES, R.C., ISBELL, T.R., and KLESGES, L.M. (1992). Relationship between dietary restraint, energy intake, physical activity, and body weight: A prospective analysis. Journal of Abnormal Psychology, 101, 668-674.

KO, C.W., HOFFMAN, H.J., LUCCHINA, L.A., SNYDER, D.J., WEIFFENBACH, J.M., and BARTOSHUK, L.M. (2000). Differential perceptions of intensity for the four basic taste qualities in PROP supertasters versus nontasters. Chemical Senses, 25, 639-640.

KOCH, A.C.E. and NESARAJAH, M.S. (1966). The ability of Ceylonese to taste phenyl thiocarbamide (PTC). Ceylon Medical Journal, Sept., 81-86.

KRANZLER, H.R., MOORE, P.J., and HESSELBROCK, V.M. (1996). No association of PROP taster status and parental history of alcohol dependence. Alcoholism - Clinical and Experimental Research, 20(8), 1496-1500.

KRANZLER, H.R., SKIPSEY, K., and MODESTO-LOWE, V. (1998). PROP taster status and parental history of alcohol dependence. Drug and Alcohol Dependence, 52, 109-113.

KRETSCH, M.J., FONG, A.K.H., and GREEN, M.W. (1999). Behavioral and body size correlates of energy intake underreporting by obese and normal-weight women. Journal of the American Dietetic Association, 99, 300-306.

KRONDL, D., COLEMAN, P., WADE, J., and MILNER, J. (1983). A twin study examining the genetic influence on food selection. Human Nutrition: Applied Nutrition, 37A, 189-198.

KRONDL, M. and LAU, D. (1982). Social determinants in human food selection. L.M. BARKER (Ed.), The Psychobiology of Human Food Selection, Chichester, Ellis Horwood.

KRUT, L.H., PERRIN, M.J, and BRONTE-STEWART, B. (1961). Taste perception in smokers and non-smokers. British Medical Journal, 1, 384-387.

LANGER, P., and KUTKA, M. (1964). Influence of cabbage on the thyroid function in man. Endocrinologica Experimentalis, 1, 303-306.

LAESSLE, R.G., TUSCHL, R.J., KOTTHAUS, B.C., and PIRKE, K.M. (1989). Behavioral and biological correlates of dietary restraint in normal life. Appetite, 12, 83-94.

LAWLESS, H. (1980). A comparison of different methods used to assess the sensitivity to the taste of phenylthiocarbamide (PTC). Chemical Senses, 5, 247-256.

LEACH, E.J. and NOBLE, A.C. (1986). Comparison of bitterness of caffeine and quinine by a time-intensity procedure. Chemical Senses, 11, 339-345.

LEGG, C., PURI, A., and THOMAS, N. (2000). Dietary restraint and self-reported meal sizes: Diary studies with differentially informed consent. Appetite, 34, 235-243.

LLOYD, H.M., PAISLEY, C.M. and MELA, D.J. (1995). Barriers to the adoption of reduced-fat diets in a UK population. Journal of the American Dietetic Association, 95, 316-322.

LOOY, H. and WEINGARTEN, H.P. (1992). Facial Expressions and genetic sensitivity to 6-n-propylthiouracil predict hedonic response to sweet. Physiology and Behavior, 52, 75-82.

LUCCHINA, L.A. (1995). 6-N-Propylthiouracil status: genetic determinant of diet-related behaviors and nutritional status in older females. Doctoral Thesis: University of Connecticut.

LUCCHINA, L.A., BARTOSHUK, L.M., DUFFY, V.B., MARKS, L.E., and FERRIS, A.M. (1995). 6-n-propylthiouracil perception affects nutritional status of independent living older females. Chemical Senses, 20(6), 735.

LUCCHINA, L.A., CURTIS, O.F., PUTNAM, P., and BARTOSHUK, L.M. (1998a). 6-N-Propylthiouracil (PROP) tasters assign higher sweetness ratings to sucrose and high-intensity sweeteners. Chemical Senses, 23, 560.

LUCCHINA, L.A., CURTIS, O.F., PUTNAM, P., DREWNOWSKI, A., PRUTKIN, J., and BARTOSHUK, L.M. (1998b). Psychophysical measurement of 6-n-propylthiouracil (PROP) taste perception. Annals of the New York Academy of Sciences, 855, 816-819.

LY, A. and DREWNOWSKI, A. (2001). PROP (6-n-propylthiouracil) tasting and sensory responses to caffeine, sucrose, neohesperidin dihydrochalcone and chocolate. Chemical Senses, 26, 41-47.

MARINO, S., BARTOSHUK, L.M., MONACO, J., ANLIKER, J.A., REED, D., and DES NOYERS, S. (1991). PTC/PROP and the tastes of milk products. Chemical Senses, 16, 551.

MARKS, L.E., STEVENS, J.C., BARTOSHUK, L.M., GENT, J.F., RIFKIN, B., and STONE, V.K. (1988). Magnitude matching: the measurement of taste and smell. Chemical Senses, 13, 63-87.

MARTIN, N.G. (1975). Phenylthiocarbamide tasting in a sample of twins. Annals of Human Genetics, 38, 321-326.

MATHERS, J.C. (2000). Dietary strategies to reduce the burden of cancer and cardiovascular disease in the UK. British Journal of Nutrition, 84, S211-S216.

MATTES, R. and DIMEGLIO, D. (2001). Ethanol perception and ingestion. Physiology and Behavior, 72, 217-229.

MATTES, R. and LABOV, J. (1989). Bitter taste responses to phenylthiocarbamide are not related to dietary goitrogen intake in human beings. Journal of the American Dietetic Association, 89(5), 692-694.

McBURNEY, D.H. and COLLINGS, V.B. (1984). Introduction to Sensation/Perception, (2nd Ed.). Englewood Cliffs, N.J.: Prentice-Hall, Inc.

McBURNEY, D.H., BALABAN, C.D., POPP, J.R., and ROSENKRANZ, J.E. (2001). Adaption to capsaicin burn: effects of concentration and individual differences. Physiology and Behavior, 72, 205-216.

McBURNEY, D.H. and PFAFFMANN, C. (1963). Gustatory adaption to saliva and sodium chloride. Journal of Experimental Psychology, 65, 523-529.

McKINLAY, S.M., BRAMBILLA, D.J., and POSNER, J.G. (1992). The normal menopause transition. Maturitas, 14, 131-135.

MELA, D.J. (1989). Bitter taste intensity: the effect of tastant and thiourea taster status. Chemical Senses, 14(1), 131-135.

MELA, D.J. (1990). Gustatory perception of isohumulones: influence of sex and thiourea taster status. Chemical Senses, 15, 485-490.

MELA, D.J. (1996). From the lab to the living room: Consumer studies of ingestive behavior. Appetite, 26, 303.

MELA, D.J. and AARON, J.I. (1997). Honest but invalid: What subjects say about recording their food intake. Journal of the American Dietetic Association, 97, 791-793.

MERIKANGAS, K.R. (1990). The genetic epidemiology of alcoholism. Psychological Medicine, 20, 11-22.

MILLER, I.J. (1987). Fungiform taste pore quantification in living rabbits. Chemical senses, 12, 684.

MILLER, I.J. and BARTOSHUK, L.M. (1991). Taste perception, taste bud distribution, and spatial relationships. T.V.GETCHELL (Ed.). Smell and Taste in Health and Disease. New York: Raven Press.

MILUNICOVA, A., JANDOVA, A., and SKODA, V. (1969). Phenylthiocarbamide tasting ability and malignant tumours. Human Heredity, 19, 398-401.

MONNEUSE, M., BELLISLE, F., and LOUIS-SLYVESTRE, J. (1991). Impact of sex and age on sensory evaluation of sugar and fat in dairy products. Physiology and Behavior, 50, 1111-1117.

MOONEY, K.M. and WALBOURN, L. (2001). When college students reject food: Not just a matter of taste. Appetite, 36, 41-50.

MORTON, C.C., CANTOR, R.M. COREY, L.A., and NANCE, W.E. (1981). A genetic analysis of taste threshold for phenylthiocarbamide. Acta Geneticae Medicae et Gemellologiae, 30, 51-57.

MOSCOWITZ, H.R. (1977). Magnitude estimation: note on what, how, when, and why to use it. Journal of Food Quality, 1, 195-227.

MURPHY, C. and GILMORE, M.M. (1989). Quality - specific effects of aging on the human taste system. Perception and Psychophysics, 45, 121-128.

NEELY, G. and BORG, G. (1999). The perceived intensity of caffeine aftertaste: Tasters versus nontasters. Chemical Senses, 24, 19-21.

NIEWIND, A., KRONDL, M., and SHROTT, M. (1988). Genetic influence on the selection of Brassica vegetables by elderly individuals. Nutritional Research, 8, 13-20.

OLSON, J.M., BOEHNKE, NEISWANGER, K., ROCHE, A.F., and SIERVOGEL, R.M. (1989). Alternative genetic models for the inheritance of phenylthiocarbamide taste deficiency. Genetic Epidemiology, 6, 423-434.

O'MAHONY, M. (1990). Cognitive aspects of difference testing and descriptive analysis: criterion variation and concept formation. R.L. McBRIDE and H.J.H. MACFIE (Eds.), Psychological Basis of Sensory Evaluation. Elsevier.

ONS. (1999). Persons in England Source: Office for National Statistics.

PALAMAND, S.R. and ALDENHOFF, J.M. (1973). Bitter tasting compounds of beer, chemistry and taste properties of some hop resin compounds. Journal of Agricultural and Food Chemistry, 21, 535-543.

PARR, L.W. (1934). Taste blindness and race. Journal of Heredity, 25, 187-190.

PEEPLES, E.E. (1962). Taste sensitivity to phenylthiocarbamide in alcoholics. Master's Thesis. Stetson University, Deland, Florida.

PELCHAT, M.L. and DANOWSKI, S. (1992). A possible genetic association between PROP-tasting and alcoholism. Physiology and Behavior, 51 OR 57?, 1261-1266.

PERYAM, D.R. and PILGRIM, F.J. (1957). The hedonic scale method of measuring food preference. Food Technology, 11, 9-14.

PETERSON, J.M. and DUFFY, V.B. (2000). Genetic variation in taste: associations with sweetness intensity, sweet liking and sweet food acceptance. Chemical Senses, 25, 638.

PONS, J. (1955). Taste sensitivity to phenylthiourea in Spaniards. Human Biology, 27, 153-160.

PRESCOTT, J., JOHNSTONE, V., and MUNRO, P. (2001). Discriminability of fat content as a function of PROP sensitivity. Chemical Senses, 26, 800.

PRESCOTT, J. and RIPANDELLI, N. (2000). Taste mixture interactions as a function of PROP taster status. Chemical Senses, 25, 640.

PRESCOTT, J. and SWAIN-CAMPBELL, N. (2000). Responses to repeated oral irritation by capsaicin, cinnamaldehyde and ethanol in PROP tasters and non-tasters. Chemical Senses, 25, 239-246.

PRUTKIN, J. (1997). PROP tasting and chemesthesis. Undergraduate thesis. Yale University.

PRUTKIN, J., DUFFY, V.B., ETTER, L., FAST, K., GARDNER, E., LUCCHINA, L.A., SNYDER, D.J., TIE, K., WEIFFENBACH, J., and BARTOSHUK, L.M. (2000). Genetic variation and inferences about perceived taste intensity in mice and men. Physiology and Behavior, 69, 161-173.

PRUTKIN, J.M., FAST, K., LUCCHINA, L.A., SNYDER, D.J., and BARTOSHUK, L.M. (1999a). PROP (6-n-propylthiouracil) genetics and trigeminal innervation of fungiform papillae. Chemical Senses, 24, 243.

PRUTKIN, J.M., FAST, K., LUCCHINA, L.A., SNYDER, D.J., and BARTOSHUK, L.M. (1999b). Spatial taste testing and genetic taste variation. Chemical Senses, 24, 604.

RAO, D.C. and MORTON, N.E. (1977). Residual family resemblance for PTC taste sensitivity. Human Genetics, 36, 317-320.

REED, D.R., BARTOSHUK, L.M., DUFFY, V., MARINO, S., and PRICE, R.A. (1995). Propylthiouracil tasting: determination of underlying threshold distributions using maximum likelihood. Chemical Senses, 20, 529-533.

REED, D.R., BARTOSHUK, L.M., GUO, S.-W., and PRICE, R.A. (1999a). Mapping a gene for bitter taste perception in humans. Appetite, 33, 228.

REED, D.R., LI, W., BARTOSHUK, L.M., and PRICE, A. (2001a). T2R1 as a candidate gene for the PTC/PROP locus: of 5p15. Chemical Senses, 26, 754.

REED, D.R., LI, W., BARTOSHUK, L.M., and PRICE, A. (2001b). Evaluation of a novel family of mammalian taste receptors on human chromosome 7Q31 as candidate genes for the PTC/PROP locus: Results of fine genetic mapping. Chemical Senses, 26, 754.

REED, D.R., NANTHAKUMAR, E., NORTH, M., BELL, C., BARTOSHUK, L.M., and PRICE, A. (1999b). Localisation of a gene for bitter-taste perception to human chromosome 5p15. American Journal of Human Genetics, 64, 1478-1480.

REEDY, F.E., BARTOSHUK, L.M., MILLER, I.J., DUFFY, V.B., LUCCHINA, L., and YANAGISAWA, K. (1993). Relationships among papillae, taste pores, and 6-n-propylthiouracil (PROP) suprathreshold taste sensitivity. Chemical Senses, 18, 618-619.

REID, N.C.R.W., BRUNT, P.W., and BIAS, W.B., MADDREY, W.C., ALONSO, B.A., and IBER, F.L. (1968). Genetic characteristics and cirrhosis: A controlled study of 200 patients. British Medical Journal, 2, 463-465.

ROZIN, P. and VOLLMECKE, T.A. (1986). Food likes and dislikes. Annual Review of Nutrition, 6, 433-456.

RUDERMAN, A.J. (1986). Dietary restraint: a theoretical and empirical review. Psychological Bulletin, 99, 247-262.

SAKAI, N. and IMADA, S. (2000). The relationship between 6-n-propylthiourea sensitivity and sensitivity for the four basic taste stimuli. Chemical Senses, 25, 234.

SALMON, T.N. and BLAKESLEE, A.F. (1935). Genetics of sensory thresholds: Variations within single individuals in taste sensitivity for PTC. National Academy of Science Proceedings, 21, 78-83.

SATO, T., OKADA, Y., MIYAMOTO, T., and FUJIYAMA, R. (1997). Distribution of non-tasters for phenylthiocarbamide and high sensitivity to quinine hydrochloride of the non-tasters in Japanese. Chemical Senses, 22, 547-551.

SCHIFFERSTEIN, H.N.J. and FRIJTERS, J.E.R. (1991). The perception of the taste of KCl, NaCl and quinine HCl is not related to PROP-sensitivity. Chemical Senses, 16(4), 303-317.

SHALLENBERGER, R.S. and ACREE, T.E. (1971). Chemical structure of compounds and their sweet and bitter taste. L.M. BEIDLER (Ed.), Handbook of Sensory Physiology: Chemical Senses 2. Berlin: Springer-Verlag.

SHEPHERD, R. (1990). Attitudes and beliefs as determinants of food choice. R.L. McBRIDE and H.J.H. MACFIE (Eds.), Psychological Basis of Sensory Evaluation. Elsevier.

SILVER, W.L. and FINGER, T.E. (1991). The trigeminal system. T.V. GETCHELL (Ed.). Smell and Taste in Health and Disease. New York: Raven Press.

SMAGGHE, K. and LOUIS-SYLVESTRE, J. (1998). Influence of PROP-sensitivity on taste perceptions and hedonics in French women. A study without retronasal olfaction. Appetite, 30, 325-339.

SMITH, S.E. (1972). Taste thresholds in drug addicts and alcoholics. British Journal of Addiction, 67, 317-321.

SNYDER, D.J., DUFFY, V.B., FAST, K. WEIFFENBACH, J.M., and BARTOSHUK, L.M. (2001). PROP genetics interact with age and sex to influence food preferences. Philadelphia, SSIB, 2001.

SNYDER, L.H. (1931). Inherited taste deficiency. Science, 74, 151-152.

SNYDER, L.H. (1932). Studies in human inheritance. IX. The inheritance of taste deficiency in man. Ohio Journal of Science, 32, 436-440.

SOLOMON, D.H. (1986). Treatment of Graves' hyperthyroidism. S.H. INGBAR and L.E. BRAVERMAN (Eds.). The Thyroid: A Fundamental and Clinical Text. Philadelphia: Lippincott.

SPENCE, M.A., FALK, C.T., NEISWANGER, K., FIELD, L.L., MARAZITA, M.L., ALLEN, F.H., SIERVOGEL, P.M., ROCHE, A.F., CRANDALL, B.F., and SPARKES, R.S. (1984). Estimating the recombination frequency for the PTC-Kell linkage. Human Genetics, 67, 183-186.

SPIEGEL, J.A. (1972). Taste sensitivity as a possible genetic marker for the inheritance of alcoholism. Undergraduate Thesis. St Louis.

STEPTOE, A., POLLARD, T.M., and WARDLE, J. (1995). Development of the motives underlying the selection of food: The food choice questionnaire. Appetite, 25, 267-284.

STEVENS, S.S. and GREENBAUM, J. (1966). Regression effect in psychophysical judgement. Perception and Psychophysics, 1, 439-445.

STONER, G.D., MORRISSEY, D.T., HEUR, Y-H., DANIEL, E.M., GALAT, A.J., and WAGNER, S.A. (1991). Inhibitory effects of phenethyl isothiocyanate on N-Nitrosobenzylmethylamine carcinogenesis in the rat esophagus. Cancer Research, 51, 2063-2068.

STUNKARD, A.J. and MESSICK, S. (1985). The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. Journal of Psychosomatic Research, 29, 71-83.

SUNDAY, S.R., EINHORN, A., and HALMI, K.A. (1992). Relationship of perceived macronutrient and caloric content to affective cognitions about food in eating-disordered, restrained, and unrestrained subjects. Journal of Clinical Nutrition, 55, 362-371.

SWETS, J.A. (1961). Is there a sensory threshold? Science, 134, 168-176.

SWINSON, R.P. (1973). Phenylthiocarbamide taste sensitivity in alcoholism. British Journal of Addiction, 68, 33-36.

TEPPER, B.J. (1998). Genetics of perception '98. 6-n-propylthiouracil: A genetic marker for taste, with implications for food preferences and dietary habits. American Journal of Human Genetics, 63, 1271-1276.

TEPPER, B.J., CHOI, Y-S., and NAYGA, R.M. (1997). Understanding food choice in adult men: Influence of nutrition knowledge, food beliefs and dietary restraint. Food Quality and Preference, 8, 307-317.

TEPPER, B.J. AND NURSE, R.J. (1997a). Fat perception is related to PROP taster status. Physiology and Behavior, 61(6), 949-954.

TEPPER, B.J. and NURSE, R.J. (1997b). PROP taster status is related to fat perception and preference. Annals of the New York Academy of Sciences, 855, 802-804.

TEPPER, B.J., TRAIL, A.C., and SHAFFER, S.E. (1996). Diet and physical activity in restrained eaters. Appetite, 27, 51-64.

TEPPER, B.J. and ULLRICH, N. (1999). Dietary restraint influences the relationship between PROP taster status and body weight in women. Appetite, 33, 234-235.

THOMAS, C.B. and COHEN, B.H. (1960). Comparisons of smokers and non-smokers. I. A preliminary report on the ability to taste phenylthiourea (P.T.C.). Bulletin Johns Hopkins Hospital, 106, 205-214.

TIE, K., FAST, K., KVETON, J., COHEN, Z., DUFFY, V.B., GREEN, B., PRUTKIN, J., and BARTOSHUK, L. (1999). Anesthesia of chords tympani nerve and effect on oral pain. Chemical Senses, 24, 609.

TUORILA, H., URALA, N., LAHTEENMAKI, L., and RITA, H. (1997). The effect of KCl and fat on perceived characteristics of cream cheeses in PROP tasters and nontasters. Chemical Senses, 22(2), 213.

TUSCHL, R.J., LAESSLE, R.G., PLATTE, P., and PIRKE, K.M. (1990). Differences in food-choice frequencies between restrained and unrestrained eaters. Appetite, 14, 9-13.

ULLRICH, N. and TEPPER, B.J. (2001). Food adventurousness clarifies the influence of PROP taster status on food preferences. Philadelphia, SSIB, 2001.

VOLICER, B.J., VOLICER, L., and D'ANGELO, N. (1983). Variation in length of time to development of alcoholism by family history of problem drinking. Drug and Alcohol Dependence, 12, 69-83.

WETHERILL, G.B. and LEVITT, H. (1965). Sequential estimation on a psychometric function. The British Journal of Mathematical and Statistical Psychology, 18(1), 1-10.

WHISSELL-BUECHY, D. (1990). Effects of age and sex on taste sensitivity to phenylthiocarbamide (PTC) in the Berkeley Guidance sample. Chemical Senses, 15, 39-57.

WHITEHEAD, M.C. BEEMAN, C.S., and KINSELLA, B.A. (1985). Distribution of taste and sensory nerve endings in fungiform papillae of the hamster. American Journal of Anatomy, 173, 185-201.

WILLS, J. (1998). The Food Bible. London: Quadrille Publishing Ltd.

WILTON, V. and GREENHOFF, K. (1988). Integration of sensory techniques into market research. Food Quality and Preference, 1, 33-35.

YACKINOUS, C.A. and GUINARD, J.X. (2000). PROP (6-n-propylthiouracil) taster status, olfactory and tactile sensitivities, fat perception and dietary intake. Faseb Journal, 14, A301.

YACKINOUS, C.A. and GUINARD, J.X. (2001). Relation between PROP taster status and fat perception, touch, and olfaction. Physiology and Behavior, 72, 427-437.

APPENDIX 1 – Food Diary
(Example of One of Seven Days)

Day one

Breakfast

Snacks between breakfast and lunch

Lunch

Snacks between lunch and Dinner

Dinner

Snacks after dinner

Can you now think over your day again and try to think about anything that you may not have immediately remembered.

If you have added salt to your plate, have you remembered to note it down?

Also if you have not already recorded your alcohol intake please do so here.

APPENDIX 2 – Food Frequency Questionnaire

Please indicate how often you eat each of the following foods by ticking the appropriate box:

	never	Less than once a week	1 - 2 times a week	3 - 4 times a week	5 - 6 times a week	Every day	More than once a day
Alcopops							
Bacon							
Biscuits							
Bitter blue cheese							
Boiled potatoes							
Broad beans							
Broccoli							
Brown bread							
Brussels sprouts							
Butter							
Cabbage							
Cauliflower							
Carrots							
Cheddar cheese							
Chilli pepper							
Chips							
Cider							
Coffee - no sugar							
Coffee - with sugar							
Cola							
Collard							
Cottage cheese							
Crisps							
Dark chocolate							
Diet cola							
Donuts							
Endive							
Fish and chips							
Fried breakfast							
Garlic							
Gin							
Grapefruit/grapefruit juice							
Green tea							
Honey							
Horse radish							
Hot curries							
Ice cream							

	never	Less than once a week	1 - 2 times a week	3 - 4 times a week	5 - 6 times a week	Every day	More than once a day
Kale							
Kohlrabi							
Lager							
Lemon juice							
Margarine							
Mayonnaise							
Milk - full fat							
Milk-semi-skimmed/skimmed							
Miso							
Milk chocolate							
Onions							
parsnip							
Pasta							
Peanut butter							
Peas							
Radish							
Red wine							
Runner beans							
Salad							
Sausages							
Soya milk - plain							
Soya milk - flavoured							
Spinach							
Sunday roast							
Swede							
Syrup							
Tofu							
Tomatoes							
Turnip							
Vodka							
Watercress							
Whipped cream							
Whiskey							
White bread							
White chocolate							
White rice							
White wine							
Whole milk							

APPENDIX 3 – Salt Questionnaire

1. I add salt to my food:

Never

Occasionally

Often

If you answered occasionally or often to the previous question, please answer the following questions:

2. I add salt to:

Just one particular food (please specify) ______________________

Two to three different foods (please specify) ______________________

More than three foods

3. I:

Taste my meal and then add salt

Add salt without tasting the food first

4. Do you add salt when cooking?

Yes

No

5. I add salt when cooking to:

Improve the cooking method

Improve the taste of the food

Both improve the cooking method and to improve the taste of the food

APPENDIX 4 – Background Questions

Please answer the following questions.

1. Name : · ______________________________________

2. Age : __________ years

3. Gender: male / female

4. Height : ___________

5. Weight: ___________

6. How many units of alcohol do you drink per week? ________units
   (Half pint/ spirit measure = 1 unit)

7. Do you smoke? yes/ no
   If so, how many per day? ____________

8. Do you have a cold at the moment? yes/ no

9. Do you have, or have you ever had an ear infection? yes/ no

10. Have you ever suffered a head injury requiring hospital treatment? yes/ no

11. Have you had a x-ray in the last 2 weeks? yes/ no

12. Do you wear a dental plate? yes/ no

13. Are you a vegetarian? yes/ no

14. Have you eaten in the last hour? yes/ no

15. Have you drunk anything in the last hour? yes/ no

16. Have you smoked in the last hour? yes/ no

APPENDIX 5 – Items in the Food Preference Questionnaire

ALCOPOPS
ARTICHOKE
BAKED POTATO
BROAD BEANS
BROCCOLI
BROWN BREAD
BRUSSELS SPROUTS
BUTTER
CABBAGE
CARROTS
CAULIFLOWER
MLID CHEDDAR CHEESE
MATURE CHEDDAR
EXTRA MATURE CHEDDAR
LOW FAT CHEDDAR
CHILLI
CHIPS
CIDER
COFFEE WITHOUT SUGAR
COFFEE WITH SUGAR
COLA
COLLARD
COTTAGE CHEESE
CRISPS
DARK CHOCOLATE
DIETCOLA
DONUTS
ENDIVE
FISH.AND CHIPS
FRIEDBREAKFAST
GARLIC
GIN
GRAPEFRUIT
GREEN TEA
HONEY
HORSERADISH
HOT CURRY
ICECREAM
KALE
KOHLRABI
LAGER
LEMON JUICE
MARGARINE
MAYONNAISE
MILK FULLFAT
MILK SEMI-SKIMMED
MLK SKIMMED
MISO
MILK CHOCOLATE
ONIONS
ORANGE JUICE
PARSNIP
PASTA
PEANUT BUTTER
PEAS
RED WINE
RUNNERBEANS
SALAD
SAUSAGES
SOYA MILK PLAIN
SOYA MILK FLAVOURED
SPINACH
SUNDAY ROAST
SWEDE
SYRUP
TOFU
TOMATOES
TURNIP
VODKA
WATERCRESS
WHIPPED CREAM
WHISKEY
WHITE BREAD
WHITE CHOCOLATE
WHITE RICE
WHITE WINE