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**PRE- AND POST-PRANDIAL HUMAN  
SCALP-EEG RESPONSE TO OLFACTORY  
STIMULATION, USING THE BRAIN  
ELECTRICAL ACTIVITY MAPPING  
TECHNIQUE**

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## DECLARATION

The research reported in this thesis is the author's own. Versions of chapters 4, 5 and 6 have been presented as papers or posters at the European Chemoreception Research Organization UK Meeting, University of Reading, November 1990; the Psychology Postgraduate Affairs Group's Annual Conference, University of Staffordshire, April 1991; the 10th Biennial Congress of the European Chemoreception Research Organization, Munich, Germany, August 1992; the British Psychophysiology Society and Health Psychology Section of the British Psychological Society Joint-Meeting, University of St Andrews, Scotland, November 1992. Abstracts have appeared in The Psychologist, Chemical Senses and the Journal of Psychophysiology. This thesis follows the style and content guidelines issued by the University of Warwick Graduate School (Guide to examinations for higher degrees by research, 1992).

## ABSTRACT

Recent psychophysiological evidence indicates that Central Nervous System activity may be directly affected by olfactory stimulation. The present thesis sought to examine the relationship between the CNS and olfactory perception in a series of three EEG experiments employing food odours as stimuli. Further aims were to explore the effect of food ingestion on psychophysiological behaviour and on the hedonic rating of odours, and to investigate the relationship between odour's affective valence and EEG asymmetry. The areas relating to olfactory psychology are reviewed in detail. Experiment 1 investigated the effects of the ingestion of a lunchtime meal and ambient food odour on the auditory oddball evoked potential. Marked P200 amplitude changes were associated with exposure to odour. In most cases, decreases in amplitude were obtained depending on the nature of the stimulus. Effects of meal ingestion were also found for P200 with the lunch group showing greater amplitude during the second (post-prandial) session than the unfed control group. A three-way interaction was obtained with the controls showing a significant decrease in P200 amplitude during the presentation of the odour of vegetable in the second session in comparison to the lunch group. No effect of odour on P300 amplitude was found. Experiments 2 and 3 examined EEG response to a variety of different actual and synthetic food odorants. Both experiments showed alterations in the theta frequency (in experiment 2, exclusively so). The effect of meal ingestion was variable with controls showing greater alpha activity than the lunch group during the second session in one experiment, but the opposite effect in the other. No alpha-related EEG asymmetry for pleasant or unpleasant odours was found in experiment 2 although asymmetries were obtained for the theta frequency. In experiment 3, however, intra-hemispheric alpha asymmetry was obtained for the most pleasant odour. No effect of lunch was found for the post-prandial psychometric rating of food odour suggesting that negative olfactory alliesthesia may not be as robust a phenomenon as gustatory alliesthesia. The hypothesis is put forward that the dominant EEG frequency for the processing of olfactory information is the theta frequency. It is suggested, however, that the effects found in this waveband may be related to the psychometric properties of the odour such as distractability and not due to the odour *per se*.

## ~CHAPTER 1~

### OLFACTORY PSYCHOLOGY-AN INTRODUCTION AND OVERVIEW

*"Taste, smell, as well as hunger, thirst, nausea and other so-called 'common' sensations need not be touched on...as almost nothing of psychological interest is known concerning them."*

**William James** (1892), Briefer Course Psychology. p.69.

#### *1.1. Psychology and the sense of smell.*

It has become a commonplace to suggest that the olfactory sense is the most neglected of the human senses: James's conclusion to his chapters on the psychology of the senses is not unique. As Engen (1983) noted a century on, "the sense of smell plays a decisive social and sexual role for animals; its importance to humans is uncertain". The ambiguity of the role of olfaction in altering human behaviour, and the ambivalence accorded to it in the social, cultural and scientific domains has been documented in a number of recent publications (Corbin 1986; Stoddart, 1990; Harrington and Rossario 1992). Although the amount of neural tissue devoted to the olfactory system is considerable (Brodal, 1981; Price, 1985), the significance of this modality in normal

human communication and information processing has not commanded commensurate importance.

The reasons for this neglect were indirectly summarised in Woodworth and Schlosberg's (1954) Experimental Psychology. This generous account of the sense of smell noted a number of psychological problems associated with the study of the olfactory system including the measurement of the sense of smell, the nature of the olfactory stimulus and the classification of odour.

One of the immediate problems lay in initial perception. Olfactory perception is a highly subjective behaviour, especially when individuals are required to label odours (Engen, 1987). Descriptors are commonly generalised adjectives based on some aspect of the odour's quality. Odours, as Zwaaardemaker (1925) remarked, have no proper names but are named after the substances that emit them. Descriptions are often referential in that odours are described as fishy, minty, woody and so on. Scientific classifications systems have attempted to crystallise such descriptors, describing odour types which range from three (von Haller, 1763) to five (Amoore, 1952; 1962 a, b), six (Henning, 1916) and seven (Linne, 1756) to eighteen (Rimmel, 1868). Although none has been found to be completely acceptable, Amoore's (1962a, b) theory of stereochemical bonding whereby five stereochemical bonding sites corresponding to a particular odour class exist on olfactory cells, is the most widely, although not entirely, accepted and practical of existing classification theories. A considerable difficulty in studying a variable which is so lexically ambiguous is this relative inability to classify and describe odours efficiently, if at all.

The relative inaccessibility of the olfactory system is also problematic. Most of what is known regarding the process of olfactory information processing and transduction at

the neural level has been derived primarily from the study of non-primates (Getchell, Bartoshuk, Doty & Snow, 1991). Sensory stimulation by odour normally results from stimulation of the first cranial nerve by volatile odour molecules. The dendrites of the projection neuron of the olfactory bulb -the mitral cell- synapse with the primary nerve, sending axons in the lateral olfactory tract (the third and most extensive branch extending from the olfactory bulb) to secondary brain structures in the "olfactory cortex" (the anterior olfactory nucleus, the frontal and temporal prepiriform cortex and the olfactory tubercle) where they form synapses with pyramidal cells. These cells, in turn, project axons to other brain structures such as the thalamus, hypothalamus, hippocampus and amygdala which provide feedback to the bulb and cortex. Eslinger, Damasio & van Hoesen (1982) have noted that it is via these extensive connections with cortical and subcortical structures that olfaction interacts with other sensory and motor systems to influence behaviour. In a later section, this role of the limbic system in olfactory perception and information-processing is considered in relation to the involvement of the amygdala. This structure has been assumed to govern many aspects of olfactory functioning from hedonic response to odour identification (Andy, Jurko & Hughes, 1975; Hughes & Andy, 1979a, b)

Odours may also stimulate the fifth and largest cranial nerve, the trigeminus, which reacts to stimulation by primarily tactile, nonolfactory stimuli such as heat, cold, pain and chemical stimulation of facial membranes. The trigeminus, however, does not appear to be involved in the perception of the "aroma" of an olfactory stimulus but is responsive to its chemico-tactile properties which explains the finding that detection of certain odours may be possible in anosmic individuals (Doty, 1975b; Doty, Brugger, Jurs, Orndoff, Synder & Lowry, 1978). Pinching (1977), for example, has suggested that musks and floral odorants, what he regarded as "pure" olfactory stimuli, were the

most efficient at detecting anosmia and hyposmia in patients with head injury and brain tumours.

The neural mechanism for the processing of olfactory information in the olfactory nerve and olfactory bulb has been thought to be transduction. Transduction takes place at the receptor level, as one might expect, but information processing (such as odour identification) may take place in the bulb and cortex (Freeman, 1983). This information processing is explained by reference to a spatial coding hypothesis which suggests that individual receptors and neurons respond differentially to specific odours. Thus for "each discriminable odour there is a subset of receptors that can respond to odour and that these receptors have a pattern of spatial location in the nasal cavity that is unlike the pattern for any other subset for another odour." (Freeman, 1983). Haberly (1985) has similarly suggested an olfactory information processing role for the piriform cortex in the form of a highly distributed ensemble code in which the olfactory cortex becomes a content-addressable memory for the association of odour stimuli with memory traces of previous odour stimuli (cf. Anderson, 1970; 1972). There is no conclusive evidence to support such a theory, however, although it would appear to explain at least the rudimentary aspects of olfactory information processing well.

Despite these recent observations, the conundrum of olfactory information coding still exists. For example, it is still not fully understood how an odour is processed, recognised, differentiated and appreciated at the neural level. Some studies have reported an idiosyncratic spatial bulbar EEG pattern to novel odours in the rabbit but have observed reliable changes in the pattern of the EEG when the odour has been previously experienced (Freeman and Schneider, 1982). This finding suggests that a spatial pattern arises in the bulb as a result of experience with a novel odour and is then stored as a template and applied to the bulb when an odour search is initiated (Freeman,

1983). The "anticipated" odour will then produce a consistent EEG spatial arrangement. A systematic investigation of this hypothesis has not yet been undertaken.

A further puzzle lies in the localisation of the specific receptors responsible for the reception of odours of different qualities, if, in fact, such selective olfactory information processing exists at the receptor level. A number of theories have purported to explain this process (Davies, 1971) but no one theory has fully accounted for the precise nature of the olfactory mechanism. As Davies himself notes, "olfactory theories are as numerous as pebbles on the beach." (Davies, 1971, p. 323). It is probable that more than one type of protein molecule (which serves as receptor site) exists on the membrane of each receptor cell (Buck & Axel, 1991) but there has been little research to confirm this.

If little is known of the olfactory system at the "bottom-up" level, what is the state of knowledge from the "top-down" approach, the avenue traditionally occupied by psychology, psychophysiology and psychophysics? Here, considerable information has come to light regarding the ability of odour to affect human psychological and electrophysiological processes (Serby & Chobor, 1992). Psychological interest in the sense of smell has largely focused on psychophysical aspects of odour and olfactory perception. However, the most striking findings relating to odour and human behaviour have emerged from an area which will be described here as *olfactory psychology*. A relatively new branch of investigation, the primary focus of olfactory psychology is the effect of exposure to odour on psychological processes-cognitive, emotional, psychophysiological, appetitive, social and those relating to survival. It is a multidisciplinary research endeavour and encompasses information from several

disciplines including neurology, social psychology, psychophysiology, cognitive science and clinical psychology.

Historical and fictional illustrations of the ways in which odour is able to manipulate emotion, mood and thought are legion (McCartney, 1968; Tisserand, 1977; Sheckley, 1978; Valnet, 1982; Lake, 1987; Suskind, 1985; Howes, 1987, 1988). Kipling, for example, wrote of smell's ability to "make the heartstrings crack". Perfume companies advertise fragrances with the aim of suggesting that their fragrance will effect a similar result. The addition of odours to domestic and other commercial products attests to the faith which manufacturers have in the ability of odour to affect the preference behaviour of their customers. What is normally absent in these examples, however, is the provision of any scientific verification. The illustrations have tremendous romantic appeal and few would deny the potential of odour to affect mood, yet the strongest evidence in support of the behaviour-altering effects of smell have been anecdotal. However, a growing body of research now exists which documents the specific effects of exposure to odour on a range of cognitive tasks, mood ratings and social behaviours. A review of this literature will be presented in **Chapter 2**.

### *1.2. The human psychophysiology of the sense of smell.*

In addition to the information from social and cognitive psychology, the relationship between odour perception and brain response has provided a limited degree of new information regarding the effects of olfactory stimulation on human perception (Lorig, 1989; Kobal & Hummel, 1991). The psychophysiology of olfactory perception has witnessed something of a resurgence of interest in the past decade with a small body of evidence highly suggestive of the role of smell in altering CNS behaviour, i.e., the perception and sensation of smell and the information-processing involved in recognising and responding to a smell may be reflected in the pattern of EEG activity.

This approach obviates the necessity of examining the olfactory system and its connections with other brain areas directly but provides evidence of the ability of a stimulus to bring about changes in the brain's electrical activity which differ significantly from its basal state. Freeman (1991), for example, as noted above, has suggested that changes in the olfactory bulb EEG reflects a template model of olfactory recognition and information processing. Other studies suggest a role for the human EEG in reflecting olfactory perception and information processing (Moncrieff, 1962; Lorig & Schwartz, 1988; Lorig, Huffman, DeMartino & De Marco, 1991; Martin, 1992; 1993b).

The majority of EEG studies has explored either the degree of activity in various EEG wavebands during some form of cognitive, perceptual or affective task (Gale & Edwards, 1983; Ray & Cole, 1985; Davidson, Chapman, Chapman & Henriques, 1990) or the pattern of the EEG in specific psychological populations, often clinical (Duffy, Burchfiel & Lombroso, 1979). Recently, it has become possible to use such a technique to study the human psychophysiological response to odour. Studies of human olfactory EEG have shown that, in particular circumstances, exposure to odour can affect the activity of the central nervous system significantly, although variably (Lorig, 1989). As noted in **Chapter 4**, the results from human EEG studies of olfactory perception are often inconsistent, a finding which is largely due to methodological differences between studies. Surprisingly, hardly any systematic study has examined the role of food odour in modifying the pattern of the EEG. This omission is unexpected given the importance of this odour in feeding and the appreciation of food flavour (LeMagnen, 1971). Odour is the primary determinant of food flavour in humans and appears to be significantly more important than taste (Mozell, Smith, Smith Sullivan & Swender, 1969; Murphy, Cain & Bartoshuk, 1977; Murphy & Cain, 1980). As the review in **Chapter 3** notes, the role of odour in the

hedonic response to food may be critical to the acceptance of that food. This role, together with the importance of odour in food appreciation in general, will be discussed further in **Chapter 3**.

Few studies, however, have examined the role of odour *valence* in affecting the EEG. Recent evidence suggests that marked hemispheric EEG asymmetries may be obtained to pictorial stimuli of different affective valence (Davidson, 1992). Greater frontal left hemisphere activation is witnessed during exposure to stimuli rated as pleasant and greater frontal right hemisphere activation is found during exposure to unpleasant, disgusting stimuli. Such findings have been interpreted as representing the biological substrates of affective processing by reflecting approach-withdrawal behaviour (Wheeler, Davidson & Tomarken, 1993). In view of the robust affective qualities of odour (Schiffman, 1992), one might expect to obtain similar EEG asymmetries to those found with pictorial stimuli by employing olfactory stimuli if affective information is perceived by the two senses are processed in a similar fashion. Processing of odour has frequently been associated with the involvement with some of the subcortical structures found in the limbic system (Takagi, 1989). If processing of an odour's affective property is mediated by parts of the limbic system, it is arguable that the EEG response will be different from that to visual stimuli whose processing relies less heavily on these structures. This hypothesis assumes, however, that the limbic system's involvement in processing odour is real and considerable and that the subsequent neural connection between this system and the neocortex is also considerable. In **section 2.6** of **Chapter 2**, this hypothesis will be considered in more detail. Whether odours perceived as pleasant and unpleasant are processed asymmetrically has not been systematically investigated. This possibility that the pleasantness and unpleasantness or any other psychometric property of the odour may generate significant EEG asymmetries will be considered in **Chapter 4**.

### *1.3. The aims of the present thesis.*

The experiments reported below are an attempt to answer some of the questions considered above. The first question concerns the extent to which odour, specifically food odour, may directly affect the human CNS (as measured by spontaneous EEG and an oddball ERP paradigm). Previous studies have sought to answer this by employing various odours and various methodologies thus often giving rise to contradictory and inconsistent findings. In the present experiments, stimuli will be restricted to a selection of food odours rated as pleasant or unpleasant. The importance of this affective distinction is related to the a second aim of this thesis.

This role of "hedonics" in the appreciation of smell is the focus of the second question addressed below. The odour of food is an affectively potent stimulus (LeMagnen, 1971; Pager, 1977). It has been found to sharpen appetite and increase salivation (Legoff & Spiegelman, 1987; Lee & Linden, 1990; 1992). Its appreciation may also be affected by the nutritional state of the subject so that a hungry individual will rate it as more pleasant than a sated one (Cabanac, 1971; 1979). More marked hedonic responses can be seen to universally repellent odours (Dravnieks, Masurat & Lamm, 1984). The odour of spoiled food, for example, is a useful and potent stimulus acting as an effective warning signal (Rozin & Vollmecke, 1986). Recent neuro- and psychophysiological evidence suggests that particular emotional experiences may be mediated by different brain regions and may be associated with increases or decreases in EEG activation in given brain areas (Davidson, 1984; 1992). Left frontal lobe lesions, for example, have been found to flatten euphoria and result in depression (Gianotti, 1972); frontal/anterior EEG alpha asymmetries are evidenced as a result of experiencing emotion of opposing valence (positive versus negative) (Davidson, 1984; 1992). This evidence suggests the possibility of measuring how the brain processes the hedonic

component of odour. The discussion included in **Chapter 4** argues strongly that such an approach is not only an obvious one but also highly logical.

The final question concerns the relationship between meal ingestion, EEG response and hedonic rating of food odour. Would an odour rated pleasant before lunch, for example, be rated as equally pleasant after lunch? Furthermore, if this is so, would the asymmetries suggested above, occur as a result of this change in the hedonic rating? Evidence suggests that the ingestion of food may alter brain metabolism and may affect the appearance of certain components of the Event-Related Potential (Geisler & Polich, 1992a, b), described in **Chapter 4**. Related evidence suggest that the combination of satiety and exposure to food odour may produce significantly different effects on the EEG than the combination of hunger and exposure to food odour (Stacher, Bauer & Steinringer, 1979). Thus, the present thesis seeks to investigate the psychophysiological and psychometric responses to food odour before and after the consumption of a meal. The experiments exploring this relationship will be presented in **Chapters 5, 6 & 7**.

First, however, a critical review of the areas of olfactory psychology, and the effects of food and odour on behaviour and the EEG is presented (**Chapters 3-5**). These chapters critically evaluate current evidence in support of the effects of odour and the consumption of food on cognitive, social and affective behaviour and review psychophysiological techniques which may be able to measure and quantify these responses more effectively. They will suggest ways in which it is possible not only to study the effects of odour and food ingestion on Central Nervous System activity but also suggest how different patterns of brain activity might be evidenced as a result of experiencing different odours and as a result of experiencing different states of nutritional satiety.

## ~CHAPTER 2~

### CAN ODOUR INFLUENCE BEHAVIOUR? A REVIEW AND CRITIQUE OF OLFACTORY PSYCHOLOGY

*"That is horse piss and rotted straw, he thought.  
It is a good odour to breathe. It will calm my heart.  
My heart is quite calm now."*

Stephen Daedalus in Portrait of the Artist (1916)  
by James Joyce

#### ***2.1. Olfactory psychology: a definition.***

A number of recent psychological studies have reported changes in human behaviour as a result of exposure to odour. This new endeavour has attracted various nomenclatures such as osmotherapy and, more germanely, aroma-chology (Green, 1988). Osmotherapy adequately describes an area examining the possible therapeutic effects of odour but does not describe the effects of odour on non-health-related behaviours. Aromachology is an unfortunate solecistic compound which makes little morphological or semantic sense. The term '*olfactory psychology*', introduced in

**Chapter 1**, will be employed here to describe those areas which examine the psychological effects of exposure to odour. As noted below, the effects of odour are varied and often inconsistent but suggest some role for odour in mediating aspects of behaviour.

*2.2. What is the use of smell? Some social consequences.*

Baron (1988) in a series of experiments designed to investigate factors affecting interpersonal behaviour reported a number of changes in person perception and social behaviour resulting from exposure to odour. Female confederates wearing perfume and dressed informally for a (pseudo-) interview were rated as more romantic, friendly and warm by male interviewers than were fragrant, formally-dressed women (Baron, 1981). Fragrant individuals were given lower intelligence and friendliness ratings by male pseudo-interviewers than were non-fragrant individuals but not by female interviewers (Baron, 1983). (Male interviewers also rated themselves as significantly poorer interviewers when applicants wore perfume). Similarly, those fragrant female applicants also emitting high levels of non-verbal behaviour were given less positive ratings than their non-perfumed, low-level behaviour counterparts by male interviewers (Baron, 1986). Contrary to the male subjects in Baron (1983), males rated the perfumed applicants as more attractive than they did non-perfume-users. These male subjects also recalled significantly less information about the perfume users than did female interviewers.

These findings are particularly striking since they appear to suggest a potent role for odour in modifying cognition. It is difficult to determine, however, what element of the context, the fragrance or the user was instrumental in effecting these changes. For example, post-experimental ratings of the odours on psychometric dimensions such as pleasantness and strength might have helped eliminate hedonic and intensity factors. It

is arguable, for example, that a strong and over-bearing perfume or a highly unpleasant one may have radically altered the assessment of the candidate. Thus it may not have been the impression of "impression management" which resulted in the attribution of negative characteristics but the perception of specific psychophysical properties of the fragrance which are transferred to the fragrant subject.

Several other aspects of these studies raise important methodological and conceptual questions. For example, Fiore (1992) noted that the floral fragrances used in Baron's (1981) study and psychometrically rated in her own were those not associated with "traditional male" traits compatible with job success (e.g., assertiveness) and may thus have affected subjects' evaluations accordingly. It is not known whether the confederates were blind to the aims of the experiments or how realistic were the conditions in which the experiment took place. Furthermore, the employment of different sexes as confederates and/or subjects makes it difficult to extrapolate the results, all other factors remaining constant, to both males and females: Baron (1981) used only female confederates and male participants (interviewers) whereas Baron (1986) employed only female applicants. The studies have also focused on specific, isolated elements of the 'interview situation' and manipulated those elements exclusively. Other factors such as the "hard-to-get" phenomenon appear to play a more critical role in the acquisition of employment opportunity and in the perception of candidates as desirable (Williams, Radefeld, Binning & Sudak, 1993). These reservations considered, however, the marked sex effects are not without some note. They do, at least in some specific, well-controlled contexts, illustrate the hypothesis that odour is capable of influencing impression formation, whether positively or negatively. The question which then arises is: To what extent is it influential?

### 2.3. *Olfaction: its common roles* .

Olfaction plays a common, if limited, role in much of the repertoire of human behaviour. Its traditional role as a natural caveat indicating the dangers of spoiled food, fumes, gases and smoke and contributing to the appreciation of food flavour) attest to the practical uses to which odour is put. As Milne and Milne (1962) remark :

*"Without the mysterious nasal sense our meals would be dull indeed-as though we had a perpetual head cold. So long as we continue to get our nourishment in the conventional way, rather than as pills to be swallowed untasted, the human nose-of whatever size or shape-is here to stay"* (p145).

This "perpetual head cold" phenomenon is attributable to the nasal chemoreceptors and nasopharyngeal receptors whose inability to function effectively results in temporary anosmia. Individuals normally remark that the eaten food has lost its taste although if asked to identify the taste of the food (as sweet, sour, salty and bitter) they are able to do so. Identification of the actual food by mouth sensation alone, however, is extremely difficult. When chemoreceptors are free to operate normally, food can be smelled and identified (Patrick, 1899; Mozell, Smith, Smith, Sullivan and Swender, 1969; Jellinek, 1985; Lawless, 1991a). This function of odour will be returned to later in **Chapter 3**.

A less well-documented use for odour is as an attractant. The use of odour in this way is common in the animal kingdom where odour signals affect behaviour more significantly than they do in the human kingdom (Stoddart, 1980; Albone, 1984). Attractants in the human kingdom, however, are not normally those secreted by sweat glands but are artificial fragrances. A decade of research on the relationship between

human semiochemistry and attraction has yielded sparse and inconclusive evidence for the existence of a human pheromone (Schaal & Porter, 1991; see **Appendix E**).

Casual observation would suggest that odours are thought to affect behaviour in an instrumental way. Their use in commercial products to add "freshness" or to give the attractive scent of X, Y, and Z flowers is widespread (Gibbons, 1986). For example, leather odour is sprayed on seats of old motors, popcorn smell is dispersed in cinemas, a faint scent is added to linen by some launderettes to create an "out-of-door freshness", the odour of baking bread is pumped to the entrance of a supermarket to entice customers (Selling by Smell, 1957; Elliott, 1962; Swallowell, 1990). This is the contingent, "nonfunctional" use of odour: the specific use of an odour to enhance the appeal or pleasantness of item. Whether such manipulations actually influence behaviour, however, is questionable. A recent study has reported an increase in time spent shopping at a large textile department store when certain odours permeated the air with the odour exerting its optimum effect in the afternoon (Nixdorf, Teerling and Koster, 1992). Carefully-controlled and designed studies, however, are few.

#### *2.4. Olfactory influences on affect and cognition.*

The majority of studies examining the effects of exposure to odour on mood and cognition tend to use ambient odours in an environment where a subject completes a particular perceptual or cognitive task, mood questionnaire or a rating scale. The general effects appear to be variable, although performance on certain tasks is particularly susceptible to the influence of smell. There also appears to be a difference in the way that pleasant and unpleasant odours exert their effects on task performance and mood, with unpleasant odours tending to produce negative effects and pleasant odours, positive effects.

#### *2.4.i. Learning, memory and cognition.*

Memory for odour is markedly resistant to time, easily accessed and tends to be characterized by a high degree of emotion, clarity and vividness (Laird 1935; Engen & Ross, 1973; Hertz and Cupchik 1992). Odours used as retrieval cues, however, are only moderately successful and appear to be no better or worse in enhancing autobiographical retrieval than stimuli in other sensory modalities (Rubin, Groth & Goldsmith, 1984; Martin, 1993b). It is possible that the presence of an olfactory effect, but not olfactory superiority, in "Proustian" experiments may be due not to the direct result of stimulation by an olfactory stimulus *per se* but to some form of cognitive mediation such as the application of a verbal label. For example, equating stimuli in designs requiring cross-modality manipulations is difficult. As Rubin *et al* (1984) suggest, if two stimuli from two different sensory modalities are matched by having the same referent, the links to memory may not be direct but may be mediated through each other. Eich (1978) reported a facilitating effect of odour on word recall only when the odour was mediated by a verbal association. Despite recent reviews of the Proust phenomenon (Richardson & Zucco, 1989; Schab, 1991; Schab & Cain, 1991; Goldman & Seamon, 1992), there continues to be an absence of information regarding the precise nature of this mechanism.

Other forms of cognitive improvement following odour exposure have been found on photograph recognition (Huebner, Lyman & Hertel, 1992), slide recognition (Cann & Ross, 1989) and word recall (Schab, 1990; Smith, Standing & deMan, 1992). This latter finding has been attributed to a mechanism similar to encoding specificity (Tulving & Thompson, 1973). Odour-related improvements have also been reported on a Remote Associates Test (almond, muguet vs butyric acid: Ehrlichman & Bastone, 1991), and a 40-minute vigilance task (peppermint, muguet vs clean air: Warm, Dember & Parasuraman, 1991). Impaired task performance during exposure to odour

has been found in mental arithmetic tasks (lavender: Ludvigson & Rotman 1989; traffic air: Lewis, Baddeley, Bonham & Lovett, 1970), a vigilance/detection task (traffic air: Lewis *et al.*, 1970), and a visual detection/reaction time task (galaxolide: Lorig, Huffman, Demartino & Demarco 1991).

Although this evidence would indicate an influential role for odour in positively and negatively manipulating test performance, not all types of performance appear to be influenced by olfactory stimuli. Tests of memory recall, vocabulary and mood using lavender and cloves (Ludvigson & Rottman, 1989); a risk-taking test, an optimism-pessimism test and an altruism test using muguet, almond, thiophene and butyric acid (Ehrlichman & Bastone 1991) and the Torrance Test of Creative Thinking using lavender, lemon or dimethyl sulphide (Knasko, 1992) have reported non-significant results. The selective nature of the deficits in task performance observed in these experiments suggests that exposure to odour will only be beneficial, or detrimental, during the performance of specific tasks. Test of vigilance, for example, appear to be highly susceptible to the beneficial effect of odour. Others such as mental arithmetic are associated with relatively poorer performance. However, it is likely, given the evidence regarding the hedonic properties of odour and from studies in the attention literature, that task performance may be more affected by some odours than by others. The discrepancy found between good and bad task performance may be attributed to exposure to pleasant and unpleasant odours respectively.

For example, aversive sensory stimuli are known to selectively impair performance on certain tasks. Unwanted or uncontrollable noise induces negative affect (eg, Konecni, 1975), negatively affects the hedonic ratings of odour (Winneke, Hedler & Koeppe, 1989) and impairs the accuracy of task performance as well as short-term memory (see Dejoy, 1986; Jones & Broadbent, 1991 for reviews). Other aversive factors such as

anxiety, heat, fatigue and sleep loss have also been found to affect speed and accuracy of performance (Broadbent, 1971; Davies & Parasuraman, 1982). Arguably, the behavioural measure of this impaired performance is distraction (Broadbent, 1971). The loudness or offensiveness of the stimulus is powerful enough to distract the subject from the the task being completed which consequently results in poor performance. The distraction in those tasks undertaken in the presence of odour may be due to the psychometric properties of the odour. The literature suggests that two likely psychometric candidates might be (i) odour intensity and (ii) the odour's hedonic properties. The relationship between these two dimensions is strong. For example, Doty (1975b) found that ten intense chemical odours were commonly rated as less pleasant than their weaker counterparts. Similar effects have been reported by Henion (1971) and Moskowitz, Dravnieks & Gerbers, 1974). A comparison of various suprathreshold odorants, however, has found that some odours are rated as distinctively different in pleasantness from others (Dravnieks et al, 1984; Pangborn, Guinard & Davis, 1988).

#### *2.4. ii. Alteration of affective and expressive response to odours.*

Brewin (1988) has noted that the term "affect" refers to a broad number of descriptive categories including mood, feeling, attitude, preference, evaluation and emotion. The consensus among emotion theorists is that emotional responses are characterised as brief, organized, difficult to control and involve complex patterning across a number of different cognitive systems (Ekman 1982; Izard, 1977; Davidson, 1984). Mood, conversely, is characterized by a much longer latency of response (which may last from an hour to many days).

The salience of affect in olfactory perception has been explicitly described in early studies by Beebe-Center (1930; 1932). Judgements of olfactory stimulation are

normally made along a pleasantness-unpleasantness axis with the factors of intensity, identifiability, familiarity and experience additionally modulating the subject's affective response to an odour (Doty, 1975b; Moskowitz, Dravnieks & Klarman, 1976; Moskowitz, 1978; Engen, 1982). A recent review has suggested that the affective component is the most common factor in Factor- and Multi- Dimensional Scaling analyses, concluding that these scaling and judgement procedures demonstrate the "saturation of odor experience with hedonic tone" (Ehrlichman & Bastone, 1992). Although evidence would suggest that this is a plausible interpretation, the assumption that the hedonic component is the dominant dimension has been criticised for the limited range of odorants that these MDS studies employ (see, e.g., Carrasco & Ridout, 1993).

Throughout the odour pleasantness literature there is reference to the hedonic quality of smell. The term "hedonic" is frequently used in psychological studies, describing responses in areas as diverse as experimental aesthetics and appetitive behaviour. A concrete definition of the term, however, is less apparent: Its validity has not been questioned, largely because of its usefulness as a descriptive dimension. Primarily, however, *any hedonic scale evaluates a stimulus along a pleasant-unpleasant dimension*. Although the subjective nature of odour pleasantness has been evident in the literature on psychophysics, there do appear to be some odours which elicit stereotypical responses (Dravnieks et al, 1984).

#### ***2.4. a) Field experiments.***

Explicit effects of unpleasant odour on behaviour have been reported in a number of studies of environmental pollution as well as in laboratory, task-based experiments. Dravnieks *et al* (1984) list the hedonic descriptors of over a hundred common odorants with most of the expected unpleasant odours given low hedonic tone ratings.

Unpleasant smells emanating from rotting food, meat and vegetable plants, rubbish dumps, landfill gas, pulp and paper mills, polluted watercourses, chemical and oil plants, cigarette smoke and diesel vehicles are common olfactory irritants (Goldsmith, 1969; Lindvall & Radford, 1973; Cederlof, 1964; Flesh, Burns & Turk, 1974; Ury, Perkins & Goldsmith, 1972; Cain, Leaderer, Isseroff, Berglund, Huey, Lipsitt & Perlman, 1983; Cram & Parkinson, 1992; Ziem & Davidoff, 1992; Shusterman, 1992; Tucker, Leaderer, Molhave & Cain, 1992). Bell, Schwartz, Petersen & Amend (1992) report that two-thirds of the 620 students tested in their survey reported feeling ill whenever they smelled one or more of five environmental chemicals. Knasko (1992) found that a group exposed to the odour of lemon reported significantly fewer symptoms of ill-health than a group exposed to unpleasant dimethyl sulphide.

Notable changes in behaviour have been associated with non-laboratory environmental "olfactory" factors: Decreased attendance to a zoo and an indoor museum has been reported during high levels of oxidant and carbon monoxide (Chapko & Solomon, 1976), whereas lower exam scores and increased anxiety levels have been found in non-smokers exposed to tobacco smoke (Kidd, 1973; Jones, 1978). The detrimental effects of tobacco smoke on the mood and behaviour of non-smokers has been widely documented (Weber-Tschopp, Jermini & Grandjean 1976; Jones & Bogat, 1978; Zillmann, Baron & Tamborini, 1981; Moschandreas & Relwani, 1992).

#### *2.4. b) Laboratory-based experiments.*

The undesirable effects of malodour in laboratory-based studies have been found by a number of authors (Rotton, Frey and Soler, 1978; Rotton, Frey, Barry, Milligan and Fitzpatrick, 1979; Rotton, 1983; Ehrlichman and Halpern, 1988). Increases in the individual's negative behaviour and mood are normally associated with the subject's exposure to a foul-smelling odour. Subjects exposed to an unpleasant smell are also

more inclined to rate similar strangers more highly than they would dissimilar strangers (Rotton *et al.*, 1978; 1979). Rotton (1983) reported that women rating paintings and black and white photographs in a room polluted with ethyl mercaptan gave significantly lower scores of "well-being" to the photographs and judged the pictures to be less professional and less worthy (but no less tasteful) than did subjects in an unpolluted room. These subjects also reported lower feelings of pleasure and levels of arousal than subjects in the air-conditioned room. In Rotton's (1983) study, the longer the exposure to the malodour the less pleasure was taken in completing the task. This again would indicate the generation of negative affect by an aversive stimulus. Subjects detected fewer proof reading errors in the polluted room but detected more when moved to an unpolluted room. Following this experiment, subjects were taken to another unpolluted room and asked to solve a series of puzzles, the first and second of which were insoluble (a measure of frustration). Those exposed to the malodour attempted fewer puzzles after a thirty minute exposure to the odour.

The opposite effect, whereby a pleasant odour enhances affect and performance has been reported (Baron, 1990). Subjects undertaking a negotiation task in a room sprayed with a pleasant-smelling air freshener reported setting significantly higher negotiation goals and rated their estimated self-efficacy much higher than subjects in an unscented room. These subjects also indicated that they would attempt to attain a higher share of available funds. In practice, subjects in the scented environment gave away slightly more monetary concessions and reported weaker tendencies to resolve future conflict through avoidance and competition than did those in the non-scented room. They did, however, rate themselves as more positive, pleasant and good, a finding which may be related to evidence suggesting that elevated positive affect increases confidence in one's ability or judgement (Williams & Keating, 1987). These subjects also had high expectations of themselves and of their performance. Similar effects on

mood have also been obtained with the odour of chamomile. This odour was reported to reduce self-reported negative mood significantly in comparison with an inert placebo in female subjects asked to visualize negative scenes (Roberts and Williams, 1992). Subjects also tended to think that there had been more positive than negative images presented during the chamomile condition.

Experiments requiring subjects to generate memories to neutral words during exposure to pleasant and unpleasant odours have found that memories were significantly happier if retrieval took place in the presence of a pleasant odour (almond) than an unpleasant one (pyridine) (Ehrlichman & Halpern, 1988). However, the linguistic associations with almond may have been stronger than those to pyridine so that the memories may thus have been cognitively rather than affectively mediated. An unpleasant, identifiable odour may thus generate a significant number of neutral or unhappy memories since both odours used-pleasant and unpleasant- would be of "equal" cognitive status.

Aggression has also been found to be affected by exposure to odour. Angered males exposed to the perfume of "Jungle Gardenia" have been found to express a significantly higher level of anger towards a female provocateur than those exposed to no-odour or a pine-scented aerosol (Baron, 1980). The odour which the subject's perceived, however, was presented not via the confederate but on an instruction form in front of the subject. Whether the subject extended this odour to the confederate, therefore, or simply disliked the odour before him is unclear. Baron concludes that these results demonstrate that the "unquestioning faith in the benefits of perfume, cologne and similar products does not seem justified." It is notable, however, that the amount of aggression in the condition where subjects were exposed to an aerosol freshener-a similar product?-did not differ significantly from that of controls. This would suggest

that the findings are perfume-specific rather than general, a point which needs to be addressed in future investigations.

In conclusion, it would appear that odour is capable of influencing mood and cognition, negatively and positively. Its influence, however, is task- and odour- specific. Some studies have reported no effect of odour on particular tasks such as creativity and optimism-pessimism or have reported methodologically-based inconsistent findings.

### 2.5. *A caveat.*

Despite the evidence that odour may change mood and ways of thinking, not all studies which report odour-related psychological changes have used genuinely olfactory materials. Slosson (1899), for example, reported that an audience believed that a bottle of odourless water opened in front of it had a strong and peculiar odour when told that the water emitted these characteristics. Similarly, O'Mahoney (1978) persuaded a number of television viewers that they had smelled an odour in response to tones produced by a machine which the television programme duplicitously claimed would induce sensations of an odour. A large number of false alarms in subjects who claimed to be able to detect an odour when none was presented has also been reported (Engen, 1965). More recently, Knasko and Gilbert (1991) found that subjects who were told that odourless water sprayed before them was pleasantly-scented reported a more pleasant mood than subjects who were told that the same spray was unpleasant. Subjects in the unpleasant condition also reported significantly more symptoms of ill-health than subjects in the pleasant condition. Thus, it would appear from these studies that the individual's hedonic perception of an "odour" is highly malleable even when there is in fact no odour to process. The "placebo effect" is strong (Critelli & Neumann, 1984). (This influence of the placebo in so-called aromatherapy studies, and the effect of odour on health is considered in **Appendix F**)

***2.6. Summary of the behavioural effects of odour and a mention of the limbic system.***

The evidence reviewed in the preceding section supports the hypothesis that exposure to odour is able to selectively impair or enhance task performance, alter social behaviour and bring about changes in mood. One possible mechanism for the alteration as noted in **section 2.4.i.** may be related to an attentional executive which is affected by extraneous variables or by the individual's interpretation of the odour's hedonic quality, the importance of which was reviewed in **section 2.4.ii.**

In relation to this hedonic interpretation, an alternative and common explanation for the affective response to olfactory stimuli has implicated the limbic system and its -and especially the amygdala's- neural associations with the olfactory system (see, e.g., Benignus and Prah 1982; Lorig and Schwartz, 1987; King, 1988; Lorig, 1989; Bell, Miller & Schwartz, 1992). A number of authors cite this collection of sub-cortical structures as representing the brain's putative "emotional centres" (Issacson, 1974).

The neurophysiological argument for its role in olfactory perception is a persuasive one. Since an odour may elicit strong emotional responses, since olfactory afferents from the lateral olfactory tract project to the cortical and medial amygdaloid nuclei, since the amygdala is "directly" linked to the olfactory bulb, olfactory association cortex, thalamus, hypothalamus and hippocampus (Motokizawa, 1985) and since this structure has been postulated to mediate responses to emotional stimuli (Aggleton and Mishkin, 1986), then the limbic system plays some role in the interpretation and processing of olfactory stimuli.

This model is by necessity, however, crude since the extent of the impairment in olfactory perception, identification, or affective response which occurs with damage to these areas in humans is largely unknown. The limbic system's involvement in the management and mediation of emotion is commonly cited as one of the system's principal functions (see Aggleton, 1992 for reviews). Kelley & Stinus (1984) have, however, observed that there is often a tendency to oversimplify the involvement of the limbic system in the mediation of emotional processes. Most studies examining the amygdala's involvement in olfactory stimulation are based on animal responses. Tanabe, Iino & Takagi (1975), for example, report successfully recording single-cell responses to odours in the medial portion of the amygdala in the old world monkey. Anatomical investigations have shown that only the nucleus of the olfactory tract, the cortical nucleus and amygdaloid transition areas receive secondary olfactory fibres (Girgis, 1969) although Price (1985) using the antero- and retro-grade axonal tracing technique reports extensive inputs from the primary olfactory cortex to the superficial nuclei of the amygdala (the anterior cortical amygdaloid nucleus and periamygdaloid cortex), the thalamus (only if the tracer injections involve the neutral endopiriform nucleus deep in the piriform nucleus or similar deep layers in the anterior cortical amygdaloid nucleus), the hypothalamus (throughout the rostrocaudal extent of the lateral hypothalamus and at the premammillary nuclei level) and the hippocampus in rats. Furthermore, Swann (1934) and Allen (1941) report that rats and dogs continue to retain the ability to olfactorily discriminate after bilateral destruction of the amygdala.

Human studies are not particularly indicative of a more specific role for the amygdaloid complex in olfactory perception although some olfactory effects have been reported. Hughlings-Jackson and Stewart (1899), for example, associated disease of the right temporo-sphenoidal lobe with warnings of smell sensations in epileptic attacks. Penfield (1958) noted that electrical stimulation of the uncus and amygdala produced

odour sensations in conscious patients although these studies have been criticised for the relatively small number of subjects who responded to stimulation (Loftus & Loftus, 1980). Hughes, Hendrix, Andy, Wang, Peeler & Wetzel (1972) reported transient increments in indifferent hedonic judgements of odours following bilateral amygdaloid lesions. Patients presenting olfactory seizures, hallucinations or auras have been found to experience no recurrence of olfactory disturbance after amygdectomy (Chitanondh, 1966; Andy, Jurko & Hughes, 1975). Halgren, Babb, Rausch & Crandall (1977), recording from neurons in the basolateral nuclei of the amygdala, entorhinal cortex and hippocampus failed to find responses to a variety of odorants whereas Hughes and Andy (1979b) reported a decrement in the judgements of odour intensity and a greater number of errors in identifying classes of odours following amygdectomy. In patients with right temporal lobectomy where the amygdala is removed, the performance of a retrieval task requiring the memorisation of odours was significantly poorer than that of left temporal lobectomy patients. These patients, however, also performed badly on standard intelligence tests of nonverbal memory (Rausch, Serafitides & Crandall, 1977) which suggests that the memory impairment was not modality-specific. The evidence from the Hughes and Andy (1979b) study is difficult to interpret since it is unclear how much the removal of other brain tissue contributed to the deficits reported. Unilateral and bilateral removal of the anterior and posterior temporal cortex, with or without the amygdala, has been known to be associated with deficits in olfactory identification and discrimination (Potter & Butters, 1980; Eskenazi, Cain, Novelly & Friend, 1983; Jones-Gotman & Zatorre, 1988 a, b). Whether Hughes and Andy's findings therefore reflect the functioning of the amygdala or the temporal cortex is unclear.

It is clear, however, that the relationship between amygdaloid deficits and their olfactory consequences is, at present, ambiguous. However, there is a possibility that

other limbic structures including dorsal and ventral parts of the medial thalamus and the so-called Papez circuit of the hypothalamus (Papez, 1937; Nashold & Wilson, 1970), are involved in the processing of an odour (Pfaffmann, 1960; Davis & Eichenbaum, 1992), an obvious assumption when one considers the apparently extensive neural pathways leading from the olfactory bulb to these areas.

This is not to argue against some role for the amygdala in mediating the hedonic component of olfactory perception nor to deny its role in the regulation of emotional behaviours. It is possible that there is specific involvement of the amygdala in olfactory perception but at present there appears to be little direct evidence to support such an association from the human literature. It is important to consider this shortcoming since many studies cite this structure as responsible for the association between olfactory perception and affective response. As Lawless (1991b) remarked,

*"students of Proustian nostalgia need to transcend gratuitous statements about smell and the limbic system and to search for mechanisms, either on a psychological or physiological level, which will help predict the circumstances under which nostalgic recollections occur."* (p. 383).

One possible method of transcending general associations between variables is by exploring replicable metabolic or psychophysiological aspects of olfactory perception in normal, healthy subjects. Volumetric measurement of MRI scans of the amygdala and hippocampus separately during odour-related tasks, for example, is now possible (Watson, Andermann, Gloor, Jones-Gotman, Peters, Evans, Olivier, Melanson & LeRoux, 1992; Jones-Gotman & Zatorre, 1993). The EEG and ERP techniques can provide access to examining the quality of general brain-behaviour relationship at the cortical level. The use and development of the Olfactory Evoked Potential has provided

some interesting data regarding the speed and integrity of the electrophysiological processing of odour. Studies have focused on odour strength as well as its hedonic properties (Kobal & Hummel, 1991). This relationship between the activity of the brain and olfactory perception and the usefulness of EEG techniques to examine the sense of smell is discussed in **Chapter 4**.

In the following chapters, attention will focus on the effects of a specific type of odour -food odour- on behaviour, principally appetitive behaviour. The effect of food consumption on mood, cognition and on the hedonic ratings of food-related stimuli will also be considered. The effect of food consumption on the pleasantness rating of subsequent meals has been widely demonstrated (Rolls, 1986). Little is known, however, regarding a meal's effect on the perception of food odour. **Chapter 3** considers this possible modification of a food odour's hedonic rating after the ingestion of a meal.

## ~CHAPTER 3~

### FOODS AND THEIR ODOURS- THEIR EFFECTS ON CONSUMPTION AND BEHAVIOUR

*"...the pleasure of smell proper, and of taste proper, has a tendency to satisfy the mind, yielding contentment rather than craving. This is to be a pure emotion...A savoury smell may partly give a commencing pleasure of digestion, and partly bring out into keenness and relief the sense of hunger; in either case it would fire the energy of pursuit towards the full fruition."*

Alexander Bain (1855), The Senses and the Intellect, p167/170.

#### ***3.1. The psychological usefulness of food: behavioural effects.***

Historically, the ingestion of food has been associated with changes in a variety of behaviour-from those foods containing psychoactive amines to apparently innocuous substances such as chocolate, cheese and caffeine (Fredricks, 1976; Robinson, Lawler, Chenoweth & Garwick, 1986). The recent emphasis on the role of food in behaviour has focused on the respective roles of carbohydrates, proteins and caffeine in altering

alertness and performance on cognitive tasks such as reaction time, vigilance and short-term memory (Lieberman, Spring & Garfield, 1986).

The detrimental effects of the *lack* of food (malnutrition and food deficiency) on behaviour are well-known (Lozoff, 1989; Wright, 1992). Malnutrition may impair neural function (Grantham-McGregor, Schofield & Powell, 1987) and have long-term detrimental effects on I.Q. (Lucas, Morley, Cole, Lister & Leeson-Payne, 1992). Retardation of foetal cerebral maturation and cretinism often accompanies iodine deficiency during pregnancy. Psychomotor performance in deficient individuals is often impaired (Connolly, Pharoah & Hetzel, 1979) as is general intellectual performance (Dunn, 1992). The adverse effects of *eating* food are also well-documented (Pauling, 1968; Fredricks, 1976; Riperre, 1984, 1985; Seely, Freed, Silverstone and Ripperre, 1985).

### *3.2. Food consumption and cognition in adults.*

The effect of food intake on normal cognitive and affective behaviour have been observed in children's intellectual performance (Simeon & Grantham-McGregor, 1989), in adults' sensory-perceptual functioning in adults (Craig, Baer & Diekmann, 1981; Smith & Miles 1986), in short-term memory (Geisler & Polich, 1992a), in the potential to reduce peak blood alcohol level (Millar, Hammersley & Finnigan, 1992) as well as in the alteration of the synthesis and release of neurotransmitters (Wurtman, Hefli & Melamed, 1981; Leathwood, 1987).

Early research indicated that food ingestion (normally in the form of lunch) contributed greatly to the decline in intellectual and perceptual functioning evidenced post-lunch, the so-called post-prandial "dip" (Blake, 1967). Others reported that this dip was dependent on the food ingested at lunch-time and not at any other time (Christie and

McBearty, 1979; Hammer, 1951). The argument followed that ingestion during this period served to satisfy the hunger that peaks at this time of day. Hildebrandt, Rohmert & Rutenfranz (1975) and Colquhoun (1971), however, suggested that this decline is not in any way food-related but is largely due to diurnal variation, and more specifically, body temperature. Furthermore, Christie and McBearty (1979) also report that the extent of the dip may be governed by personality factors—the extent of the dip was greatest in the more stable and extraverted individual; the more neurotic and unstable individuals were not inclined to exhibit the dip to any great extent. Craig *et al* (1981) examined the hypothesis that personality may affect psychological response to food ingestion and found that, indeed, the less neurotic and more extrovert individuals performed significantly worse on a discrimination efficiency task than their more unstable and introvert counterparts after ingestion of lunch. Needless to say, those individuals who ingested the lunch also showed a significant decrement compared with those simply taken for a walk and not given lunch. The authors suggest that the post-prandial dip witnessed in this study is comparable to the effect of a complete night without sleep. The duration of this dip was not measured.

A few other studies are generally supportive of the view that ingestion of a lunchtime meal selectively impairs cognitive performance. Decrements in reaction time, mental arithmetic and vigilance tasks have been reported following the ingestion of lunch (Blake, 1971) as have impairments in sensory detection performance (Craig, 1986; Smith and Miles, 1986), although the latter of these studies, however, allowed smoking, the free-ingestion of caffeine and the free selection of food type and size. Geisler and Polich (1992a) have reported increases in recall for words recently presented (thought to be a measure of short-term memory) in those subjects who had performed the task immediately after eating lunch. These scores differed significantly from pre-lunch and 30 minutes post-lunch conditions. Smith (1992), reviewing the

available evidence concerning the effects of food on behaviour and psychological performance, concluded that post-lunch impairments are likely to be found in tasks requiring sustained attention but not in shorter tasks. Breakfast consumption has little effect on sustained attention but may improve other aspects of memory. The results, however, are suggestive rather than conclusive. The post-prandial impairments may be dependent not only on ingestion but also on personality factors, the availability of stimulants and the size and nature of the meal.

### *3.3 Nutrient-specific impairment?*

The flaw in the Smith and Miles (1986) study (that meals were freely selected and not under strict experimental control) has been highlighted by various studies in the 1980s purporting to demonstrate specific-food-related alterations in mood and performance. These generally concluded that carbohydrates and proteins evinced different effects on mood and intellectual functioning (Wurtman, 1986; Lieberman, Spring & Garfield, 1986). Spring, Maller, Wurtman, Digman and Cozolino (1982/3), for example, reported that a high-carbohydrate lunch was significantly associated with impairment in a sustained attention task (dichotic shadowing) compared with those receiving a high-protein turkey lunch but for older subjects only. Animal studies showed that different nutrients evoked different behaviours depending on the specific nutrient consumed (Fernstrom & Wurtman, 1971; Fernstrom & Wurtman, 1972; Wurtman, Hefli & Melamed, 1981). When serotonergic neurotransmission at brain receptor sites increased, changes in food intake and selection occurred. The principal mechanism governing these nutrient-related behavioural differences appeared to be precursor availability (tryptophan, a large neutral amino acid) and its influence on the synthesis and release of neurotransmitters.

Tryptophan administered in pure form increases levels of serotonin, is reported to be significantly correlated with increased drowsiness and lethargy and increases the onset of sleep (Hartman & Elion, 1977; Hartman & Spinweber, 1979; Lieberman, Corkin, Spring, Growdon & Wurtman, 1982; Lieberman, Corkin, Spring, Growdon & Wurtman, 1983; Spinweber, Ursin, Hilbert & Hilderbrand, 1983) although one study has reported female-only effects (Spring, Maller, Wurtman, Digman & Cozolino, 1982/3) and others have failed to find any tryptophan-dependent induction of sleep and drowsiness (Nicholson & Stone, 1979; Hartmann, Lindsley & Spinweber, 1983). Carbohydrate foods, although containing no tryptophan, can increase brain levels of this precursor levels (Leathwood, 1987; Lieberman, 1987).

Although tryptophan may induce drowsiness and mental sluggishness (Yuwiler, Brammer, Morley, Raleigh, Flannery and Geller, 1981), increase fatigue and reduce vigour and alertness (Lieberman *et al.*, 1982), there is little evidence to suggest that its consumption impairs psychomotor tasks (Lieberman *et al.*, 1982). There are some tasks, however, that appear to be susceptible to the influence of carbohydrates. Lieberman (1987) has argued that "since more tryptophan is available for transport into the brain, carbohydrate meals can increase brain serotonin. The effects of a carbohydrate meal thus can resemble those following the administration of pure tryptophan" (p271), presumably those of inducing drowsiness and blunting alertness. The effects of protein/tyrosine on behaviour (mood and task performance) are less clear. Studies using alertness, sleepiness, RT scores and inertia measures have found no effects of protein/tyrosine (Lieberman *et al.*, 1982/3; Leathwood & Pollet, 1982/3; Spring *et al.*, 1982/3) although older subjects reported greater tension and less calm after a protein than carbohydrate meal (Spring *et al.*, 1982/3). The implication of this finding is unclear.

Significantly lower reaction times has been reported one and three quarter hours after a carbohydrate lunch than after a protein lunch whereas no effect of carbohydrate on a dichotic listening test was reported (Lieberman, Spring and Garfield, 1986; cf. Spring *et al.*, 1983). Spring, Chiodo and Bowen (1987) suggest that the RT effect may have been attributable to the employment in the Lieberman *et al.* study of four times as many trials and intervals which were half as long as those in the Spring *et al.* study and further suggest that, as a consequence, the Lieberman study may have yielded more reliable scores. A Digit-Substitution test revealed significantly worse performance three and a half hours after a carbohydrate meal compared with a protein meal (Lieberman *et al.*, 1986). No differences, however, were found for the Wilkinson Vigilance Test, a four-choice reaction time test, a card sort task or a tapping test. The criticism has been made that not all tests of vigilance are equivalent (Lieberman *et al.*, 1986). The discrepancies found in several of these studies may, therefore, not be considered unusual or unexpected. No psychonutrition research has yet explained in any detail why some of these vigilance tests should exhibit food-dependent effects while others do not.

The conclusion of cognition-consumption studies, therefore, is that food ingestion may affect the performance of specific tasks, usually those requiring attention and normally results in performance deficits. In the following section, the effect of food ingestion on a different form of behaviour, affective response, is considered. Together with the evidence from the cognitive literature, this aspect of behaviour indicates a significant role for food and food odour in affective response and cognitive functioning.

#### ***3.4. Pre- and post-prandial response to food odour.***

A great emphasis has been placed on the role of food aroma in the mediation and precipitation of behaviour. Vonderahe (1943), for example, suggested that "the first emotional state, that of being attentively alert and ready for action, in the pursuit of food

or for flight or for mating, appears to grow out of olfactory perception". Physiological changes such as alterations in human blood glucose level (Bassi & Pascucci, 1942; Caniggia & Brogi, 1947), gastric contractions (Ginsberg, Feldman & Necheles, 1948) and salivation (Legoff & Spiegelman, 1987; Lee & Linden, 1990; Lee & Linden, 1992) have been reported to occur with exposure to food odour. Secretion of saliva and gastric and intestinal juices depend greatly on olfactory and gustatory reflexes (Bergman & Bergman, 1986).

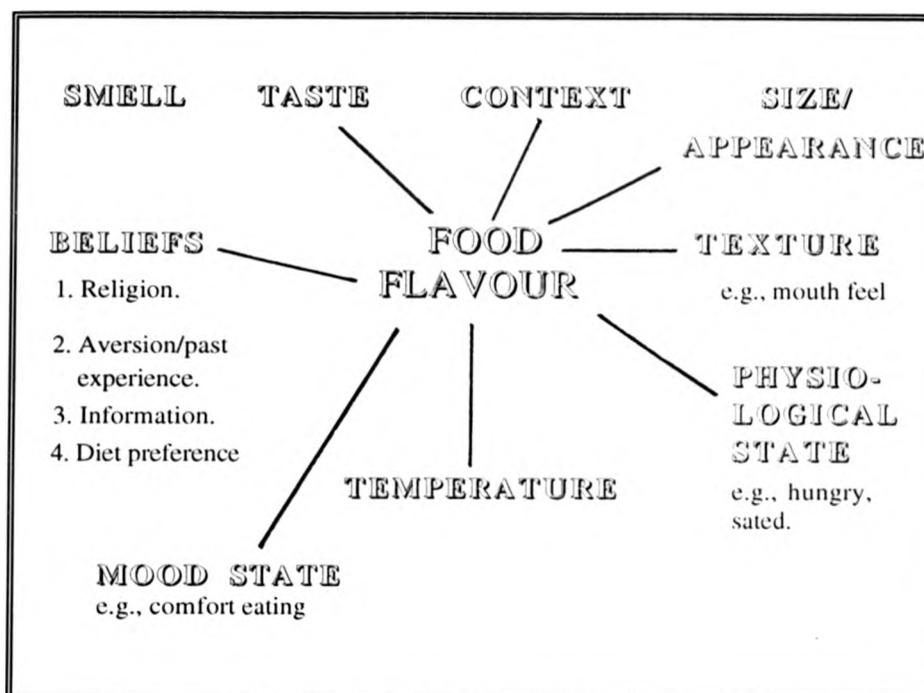
A small number of studies have shown that the affective response to the taste, smell and consumption of a food may change markedly after the ingestion of a meal, usually lunch (Duclaux, Feisthauer and Cabanac, 1973; Cabanac and Fantino, 1977; Rolls, Hetherington, Burley & van Duijvenvoorde, 1986). Duclaux *et al* (1973), for example, asked 10 subjects to rate the pleasantness of food odours (beef-bouillon, cheese, fish, honey), meal-related odours (tobacco, wine, coffee) and non-food odours (lavender, Encre de Chine) before and after the ingestion of a meal (bread, butter, ham, chips, sugared milk and orange). A control group of ten subjects did not receive a meal. Those in the meal consumption group rated the odours of cheese, beef and fish as significantly less pleasant than controls (negative alliesthesia, see **section 3.4.**) but there was no alliesthesia reported for the non-food odours or for the meal-related odours in either group.

Olfactory thresholds also appear to be affected by the ingestion of a meal, with acuity showing a decrease after lunch. Some authors suggested that appetite varied directly with acuity of the olfactory sense and could thus be measured in terms of olfactory thresholds, demonstrating in a number of studies that diurnal variations in olfactory acuity were "intimately connected" with ingestion of food (Goetzl and Stone, 1947; Goetzl and Stone, 1948) over a number of days (Goetzl, Abel and Ahokas, 1950).

decreased by ingestion (but not taste) of sugar but not by intravenous administration of glucose (Goetzl, Goldschmidt, Wheeler and Stone, 1949). Similar findings were reported elsewhere using coffee as an olfactory stimulus (Guild, 1956; Hammer, 1951) although Janowitz and Grossman (1949) found no food-related changes in acuity for coffee or any relationship between appetite suppression (by D-amphetamine) and performance of the gusto-olfactory senses. Goetzl *et al* (1950) suggest that this "occasional failure to demonstrate a significant decrease in olfactory acuity following ingestion of the noon meals may have to be explained in part by a failure of the meal to produce a sensation of satiety." (p 561). Others, however, note that the lowering of the olfactory threshold during hunger is present in some individuals but is absent in others (Furchtgott & Friedman, 1960; Berg, Pangborn, Roessler & Webb, 1963).

### *3.5. Alliesthesia and the concept of sensory-specific satiety.*

Several factors contribute to food flavour, including odour, taste, texture, temperature, manageability, appearance, context and mood (Lawless, 1991a), as illustrated in Fig A. These factors are all important determinants of food flavour although some appear to be more important than others (Rozin & Vollmecke, 1986). As noted in **Chapter 2**, when the nasal chemoreceptors including nasopharyngeal receptors are impaired or blocked, identification of food is difficult (Mozell *et al* 1969; Murphy, Cain & Bartoshuk, 1977; Hyman, Mentzer & Calderone, 1979; Murphy & Cain, 1980).



*Fig. A. represents the primary determinants of food flavour.*

A series of studies in the 1950s and 60s employing anosmics and hyposmic subjects tended to contradict this view although these studies did not monitor the extent or "completeness" of the anosmia, control for the use of extra-chemoreceptory clues and may not have undertaken accurate sensory evaluations (Clark, 1968; Clark & Dodge, 1955a,b). As Mozell *et al* (1969) argue, "these patients cannot a priori be treated as simply normal people minus the vapor-sensing input." Later, mechanically effected impairments of the nasopharyngeal receptors demonstrated that without these working receptors, the ability to identify the flavour disappears. The ability to describe the food in terms of its taste categories, however, remains intact. Thus the importance of the olfactory component in food appreciation cannot be underestimated.

In recent years, it has been argued that the internal, nutritional state of the subject is important not only to the individual's decision to acquire and ingest food but also to the hedonic rating of food-related stimuli such as smell and taste (Cabanac, 1979; Rolls, Rolls & Rowe, 1983; Johnson & Vickers, 1992). This idea is not a novel one: Aristotle noted that the smell of food odours are "pleasant when we are hungry, but when we are sated and not requiring to eat, they are not pleasant." (Ross, 1906). If subjects swallowed sugar solutions and were asked to rate sweet items, the pleasantness of sweet tastes declined; rinsing the mouth with sweet solutions did not affect the hedonic response (Cabanac, 1971). The odour of orange syrup was found to be pleasant to fasting subjects and remained pleasant when repeatedly presented. Following glucose ingestion, however, its pleasantness rating declined significantly. Thus it was argued that a "stimulus can be perceived as either unpleasant or pleasant depending on signals coming from inside the body" (Cabanac, 1971) and the term "alliesthesia" was used to describe the phenomenon. Although few experiments have examined this concept in any detail, the studies which exist broadly support the notion (Drenowski, Grinker & Hirsch, 1982; Rolls *et al.*, 1986; Warwick, Hall, Pappas & Schiffman, 1993). However, they suggest much more specific effects than Cabanac describes.

### ***3.6. Alliesthesia & sensory-specific satiety I: the laboratory studies.***

The alteration of the hedonic post-prandial rating of particular foods has been argued to be dependent on more than simple ingestion. On the basis of experiments in which a variety of different foods are presented and consumed, the idea has been suggested that satiety is the result of the perception of sensory properties of the foods, as opposed to their general satiating impact. This has been described as "sensory specific satiety" (Rolls, Rolls & Rowe, 1983; Rolls, 1986). There is a significant difference between

negative alliesthesia and sensory-specific satiety. The former refers to a "change from a pleasant sensation toward an indifferent or unpleasant sensation on the affective axis" (Cabanac, 1979)- tasting food or ingesting foods with no calorie content will have no effect on alliesthesia. Sensory-specific satiety (SSS), however, does not depend on the condition of repletion or on the physiological need for nutrients. Instead, "the rapid changes in palatability that occur during and immediately after eating depend on the sensory properties of foods, or on some cognitive process which assesses that enough of a particular type of food has been consumed" (Rolls, 1986).

A common finding in SSS studies is that if a food is eaten to satiety, then a second course of the same food will result in a reduction of intake to approximately 50 % of the first intake (Rolls *et al.*, 1981). This finding appears to reinforce the casual observation that one food eaten to fullness will not be eaten particularly eagerly or in great quantities if presented for consumption again. In this study, all foods except roast-beef produced sensory-specific satiety although not all subjects ate the same amount of the test meals (Rolls *et al.*, 1981).

As one would expect, subsequent intake is affected by previous intake. Less evidently, the food's pleasantness rating may also change. The pleasantness rating for food consumed as a one-course meal (either one of two savoury meals, a dessert or fruit) has been found to be significantly decreased when compared with foods consumed in a four-course meal (Rolls, van Duijvenvoorde & Rolls, 1984) as have the pleasantness ratings for food consumed as test materials compared with those given as meals and test materials (Johnson & Vickers, 1992). This effect of food on intake appear to be unrelated to the nutritional content of the food (Booth, Mather & Fuller, 1982; Rolls *et al.*, 1986), although Booth *et al.* reported that when subjects ate foods of different nutritional content (high or low calorie soup or jelly) and then freely ingested

sandwiches, the amount of sandwiches eaten decreased following the high-calorie meal but only after repeated experience with the foods. This would suggest that the body's internal state is capable of adjusting to its micronutrient requirements appropriately with experience, if it is given the opportunity to do so.

The role of variety in consumption has been outlined as an important one. Rolls et al (1986) reported a 60% increase in the intake of a four-course meal of sausages, bread and butter, chocolate dessert and bananas as compared with the intake of only one food. The desire to eat has also been linked with the availability of the variety of food (Johnson & Vickers, 1992). The finding suggests either an extremely generous "hedonic" mechanism whereby the body derives pleasure from various sensory sources and will allow different foods to be consumed in the regulation of this pleasure principle, or (or perhaps and) it suggests a form of survival mechanism which allows a varied selection of food (and therefore, nutrients) to be eaten without the body feeling satiated. Cornell, Rodin and Weingarten (1989), however, report that individuals continued to eat the test foods -pizza and ice-cream- after being fed to satiety. Even the sight of these foods enhanced the desire for these foods.

### *3.7. Pre and post-prandial pleasantness ratings of food.*

On the basis of the evidence reviewed above, a shift in the amount of food eaten following the consumption of particular meals would be expected. This shift has been seen to be dependent, in some instances, on the sensory properties of the food such as colour and shape (Rolls *et al*, 1982). Post-prandial shifts in hedonic ratings of food-related stimuli have also been examined in similar fashion. Consumption of tomato soup reduced the pleasantness rating of a consomme but did not affect ratings of fresh tomato (Rolls *et al*, 1986). All orange-flavoured foods decreased in pleasantness after consumption of orange jelly, although the decline in the rating of the orange segment

did not persist. Interestingly, raspberry jelly showed a strong decrease in pleasantness following ingestion of orange jelly.

Palatability also radically affects liking (Spitzer & Rodin, 1981). Johnson & Vickers (1992), for example, found that foods consumed as test meals dropped significantly more in liking than eaten foods, except for a well-liked granola mix and plain yoghurt. This drop was evidenced in all foods except for buttered roll, a finding the authors attribute to the complicated nature of the food (two foods not one) which diminished sensory-specific satiety. These authors also report that high protein meals (turkey and cheese) dropped more in liking than lower protein meals. A second experiment, to determine whether the complexity of an individual food (types of yoghurt with added components) diminished sensory specific satiety, suggested that subjects' desire to eat decreased significantly more after eating the high variety test meals when compared to the low and intermediate variety test meals. Increasing the liking of the food also did not diminish the drop in liking of food when it is eaten. There was no significant difference in the decrease in eating between the less and more well-liked foods. Time-of-day differences in food preference may also exist with both adults and children preferring "breakfast items" (scrambled eggs, orange juice, cereal) more when ingested in the morning than in the afternoon and preferring the "dinner items" (pizza, green beans, macaroni cheese) better in the afternoon than the morning (Birch, Billman & Richards, 1984).

### *3.8. Alliesthesia and sensory-specific satiety II: a critique.*

The characterisation of the phenomenon described in the above studies as "sensory-specific satiety" has been challenged. Blundell and Rogers (1991), for example, argue that the term is limited on logical grounds. A "demonstration of sensory stimulation of eating (by different food)" they argue, "does not justify the invocation of a mechanism

of 'sensory-specific satiety' ". They further argue that the methodology used to determine the satiety and hedonic ratings obtained in these studies is inappropriate and misleading. Are subjects, for example, rating how good the food *tastes*, or how good the food is *to eat*? Replications by others groups have been inconsistent or contradictory. Cornell *et al* (1989), for example, reported no effects of food intake on subsequent ingestion of the test food. Warwick *et al* (1993) reported no expected shifts in hedonic perception of food odour after the ingestion of breakfast. The only significant odour-related finding was the *increased* pleasantness of geraniol after eating. Hedonic taste responses were characteristically flattened after consumption.

Whether the term is strictly dubious on logical grounds is questionable. If the satiety experienced were not the result of some sensory-specific factor of the food, then presumably the nutritional content of the food would be the most likely satiating candidate. The Rolls *et al* (1986) and Booth *et al* (1982) studies, however, demonstrate no satiating effects of foods with different nutritional value. This is not to state that the nutritional content of food is irrelevant to intake. Booth's subsequent finding that experience with foods of different nutritional hue led to a decrease in some second-course foods provides an example that it may. However, the results obtained in the Rolls studies are sensory, or perhaps more prudently, factor-specific since the variables manipulated were quite sharply delineated.

The argument that subjects may not be rating the food's taste but how good it is to eat is, perhaps, misleading since this distinction is made by Rolls and her colleagues (e.g., Rolls, Laster & Summerfelt, 1991). Whether subjects in these experiments fail to make this distinction, or are unable to comprehend an experimenter's instructions without any assistance, is debatable. In either regard, the distinction is one which could conceivably affect only the semantic nature of the phenomenon. As suggested earlier,

factor-specific is a less presumptuous and more liberal description of the findings. What is questionable is the highly stylised and supremely-controlled nature of the experimental design. One might argue, on the grounds that the method endangers external validity, that since little interaction with others is allowed, since the food is tasted first and since a meal is foisted on the subject and is eaten to satiety, that this mirrors very poorly the common experience of eating. This criticism and that of the self-conscious nature of food ingestion in such an experimental setting has also been made by others (Lambert, Neal, Noyes, Parker & Worrel, 1991-2). The grouping of responses into general response categories also suggests the possibility that individual differences may be masked (a point also made by Blundell and Rogers), an important factor in food preference and food choice. These observations, however, probably constitute more of a suggestion for further development rather than a fundamental criticism.

### *3.9. Summary of the behavioural effects of food and food odour.*

Food ingestion appears to affect psychological performance erratically. Some studies suggest post-prandial decrements in cognitive performance (normally reaction time) others report no change or highlight the cognitive benefits of lunch ingestion (such as its effects on short-term memory). The nature of these cognitive benefits and deficits of consumption are presently unclear. Some foods, however, would appear to have highly generalised effects on human affect. Carbohydrates, for example, have been reported to induce sleepiness to a greater extent than protein foods (as noted in **section 3.3.**). Additional mood-effects have been difficult to establish in human subjects. The effect of food on satiety and hedonic response, however, appears to be more clearly understood. Cabanac has suggested that a post-prandial hedonic change in the perception of food-related sensory stimuli operates alliesthetically so that the liking of a food is dependent on whether it has been eaten or, more generally, whether the subject

is satiated. As noted in **section 3.5.**, foods eaten to satiety tend to be liked less than a palatable, uneaten food. Furthermore, this "sensory-specific" satiety may extend to food odour, although the findings for this sensory channel are less clear-cut (Ducleaux *et al.*, 1973; Warwick *et al.*, 1993). In **Chapters 5-7**, the nature of olfactory alliesthesia will be examined more practically in a series of three experiments. The alliesthesia component of these experiments will focus solely on the olfactory contribution to the hedonic response to food in order to determine the relative contribution of olfaction to post-prandial likes and dislikes.

In the following chapter, however, the effect of food ingestion on another variable, the evoked potential is considered as well as its interaction with the perception of food odour. Also examined is the more complex concept of the psychological significance of the EEG and its relevance to the measurement of human olfactory perception. A discussion is presented regarding the possibility of obtaining asymmetries in EEG as a result of exposure to odour of opposing valence. The literature relating to affect and EEG is reviewed and its relevance to aims of the thesis are outlined.

## ~CHAPTER 4~

### EEG, ERP AND OLFACTORY PERCEPTION- THE USE OF PSYCHOPHYSIOLOGY TO EXAMINE HUMAN RESPONSE TO ODOUR AND FOOD CONSUMPTION

*"As for their [EEG rhythms] 'functions', one hesitates to use the word, they may be not more than the waste-end product of some cerebral processes, perhaps the smoke from smouldering biochemical fires."*

**R.W. Moncrieff** (1962)

*"The prudent application of EEG holds great promise for increasing our understanding of human CNS activity and especially the influence of odour on that activity."*

**T.S. Lorig** (1989)

#### **4.1. Psychological concomitants of EEG activity.**

The majority of electroencephalogram (or EEG) studies suggests that this measure is useful tool in the investigation of psychological variables. Spatial and motor tasks (Beaumont, Mayes and Rugg, 1978; Rappelsberger and Petsche, 1988), verbal tasks (McKee, Humphrey and McAdam, 1973; Davidson, Chapman, Chapman and Henriques, 1990), mental imagery (Furst, 1976; Ornstein, Johnstone, Herron and Swencionis, 1980; Berfield, Ray and Newcombe, 1986), stress (Linke, Reuter and

Kurthen, 1989) and experience of emotion (Davidson, Schwartz, Saron, Bennett & Goleman, 1979) produce a significant alteration in the pattern of the EEG.

Berger's (1929) discovery of the EEG and the prediction by Walter (1953) that these 'brainwaves' might represent a window on the brain has fueled a number of studies of the effects of cognitive, affective, motor or perceptual task on brain behaviour. The most commonly reported task-related changes are found in the alpha frequency (8Hz-13Hz) where decreases are thought to reflect "desynchronisation" or "alpha-blocking" (Berger, 1929). Collections of cells respond in a similar fashion until some external or internal stimulus occasions a shift in frequency of response. According to the International Federation of Societies for Electroencephalography and Clinical Neurophysiology (IFSECN, 1974) alpha is "best seen with eyes closed and under conditions of physical relaxation and relative mental inactivity. Blocked or attenuated by attention, especially visual and mental effort." Concomitant increases in beta (14Hz-30Hz) may also be witnessed with alpha blocking. The alpha frequency is characterised as the normal adult waking EEG and is thought to reflect "relaxed wakefulness" (Lindsley, 1952; Niedermeyer, 1987). Some authors have sought to relate changes in this frequency to arousal. Wilson, Orne & Pakewitz (1976), for example, report reduced alpha feedback in subjects exposed to the threat of shock. They also report, however, that several subjects reported the opposite, showing increases in alpha density. The arousal relationship is, therefore, highly ambiguous. Indeed, similar to the use of the term 'hedonic' in psychology and the use of the terms 'stimulant' and 'depressant' in caffeine/alcohol studies, it is uncertain exactly what the terms used actually signify in their respective contexts. As a descriptive concept it is useful but as valid construct it may be questionable.

An early EEG study by Adrian and Mathews (1934) reported that under an eyes-open condition, a visual input condition and during the performance of an arithmetic task, "blocking" of the alpha rhythm occurred. Changes in alpha are thought to be inversely related to the degree of activation in a given area (Lindsey & Wicke, 1974) so that a decrease in alpha indicates greater underlying activation. Alpha-related changes in task performance have, to a great extent, dominated investigations of task-related human scalp EEG changes. Doyle, Ornstein and Galin (1974) reported greatest task-dependent asymmetry in alpha; Morgan, McDonald and Macdonald (1971) reported relatively lower alpha over the right hemisphere in most subjects during a performance of a spatial task. Similar cognitive and affective task-related alpha asymmetries in the EEG have been found by others (Galin and Ornstein, 1972; Dumas and Morgan, 1975; Butler and Glass, 1976; Davidson and Schwartz, 1977; Ehrlichman and Wiener, 1979; Ornstein, Heron, Johnstone and Swencionis, 1979; Schaffer, Davidson and Saron, 1983; Tomarken, Davidson and Henriques, 1990; Jones and Fox, 1992).

Some studies, however, report no alpha asymmetry for specific tasks such as verbal and visuospatial tasks but report asymmetries in the theta frequency, with increased right activation during a visuospatial task only evident in males (Rugg and Dickens, 1982). Others report increased beta coherence in females for the right temporo-occipital areas during a mental cube rotation task and increased left hemispheric beta in males (Berfield, Ray and Newcombe, 1986). On the other hand, Rappelsberger and Petsche (1988) report more right-sided local theta coherence in males but greater left hemisphere involvement in females. In the beta frequency, females showed parietal increases in coherence in the left side but greater temporo-occipital coherence in the right hemisphere. In males, coherence was asymmetrically right-sided for both areas. The EEG, therefore, although not fully exploited, provides an efficient way of

observing psychophysiological concomitants of mental performance and of the variables capable of affecting mental performance .

#### *4.2. Alpha desynchrony: artifact or task-related?*

The notion of desynchrony and, in fact, any EEG task-related change is not as clear-cut as it appears. Gevins, Zeitlin, Doyle, Yingling, Schaffer, Callaway and Yaeger (1979), for example, found no lateralised EEG differences in response to different tasks but did report bilateral involvement during performance of complex cognitive tasks. EEG patterns distinguished between complex, uncontrolled tasks (mental paper folding, writing from memory, scribbling, Koh's block design, reading) but not controlled ones (visual fixation, block rotation, letter substitution and serial arithmetic). These authors suggest, on the basis of their own findings, that there is no support for the hypothesis that asymmetrical EEG task-related differences reflect cognitive processes (despite a strong rebuttal from Davidson and Ehrlichman, 1980). The conclusion was further supported by a number of criticisms Gevins, Doyle, Schaffer, Calloway & Yeager (1980) made of studies purporting to demonstrate "left-right" hemispheric EEG differences. Studies purporting to show differences should, for example, minimise differences between tasks, minimise performance-related differences between tasks (so that effort and difficulty are equal), eliminate differences in efferent activities, ensure that useable data reflect recordings that contained tasks which were correctly performed and reject all extracerebral artifacts.

All of the studies cited by Davidson and Ehrlichman (1980), contained at least two methodological shortcomings which made any conclusions from the data suspect. Yingling (1980) has argued that "the lack of active motor involvement eliminates the necessity for much of the cortex to be involved, and thus the scalp EEG does not show a clear pattern of lateralised activity" suggesting that movement-related EEG produced

by writing cannot be attributed to artifact when it is an essential part of "the coordinated perceptual-cognitive-motor activity which is the primary function of the brain". This would be true were one able, for example, to distinguish between scribbling and writing from memory on the basis of EEG. In the Gevins *et al* study, these two tasks were the only two to fail to reach significance in terms of percentage accuracy in distinguishing between tasks. The most striking difference in tasks was found between visual fixation and Koh's block design. Thus, it would appear that Gevins and his colleagues have a point when requesting that tasks be relatively free of limb movements, stimulus characteristic differences and performance-related differences. Davidson, Chapman, Chapman and Henriques (1990), for example, successfully demonstrated greater power suppression in the hemisphere most engaged in processing (in the alpha, beta, delta and theta bands) or greater power in the opposite hemisphere during the performance of two psychometrically-matched tasks (word-finding and dot localisation). The verbal task occasioned significant greater alpha and theta suppression in the left hemisphere than did the spatial task. Davidson and his colleagues have also reported fairly robust alpha asymmetries to pictorial stimuli of opposing valence (Tomarken, Davidson and Henriques, 1990; see sections 4.14-16.). Thus, it would seem that under tightly controlled conditions, significant shifts in the pattern of the EEG can be obtained using cognitive, perceptual or affective stimuli. The precise nature of the EEG, however, and its function in relation to information processing has been widely debated (see Niedermeyer & Lopes da Silva, 1987). The debate is also fuelled by the difficulties inherent in EEG recording itself, some of which are surmountable and some of which are less easy to overcome.

*4. 3. Electroencephalography: The technique, the activity and its problems.*

Electroencephalography (or EEG) is a complex branch of electrophysiology. The complexity begins with the generating source of the EEG and its respective wavebands (Nunez, 1981). Recent attempts at determining this source for each frequency using Fast Fourier Transformation dipole approximation have confirmed some early observations (Adrian & Yamagiwa, 1935) such as a posterior bilaterally symmetrical generator for alpha, hippocampal generator for theta and so on (Michel, Lehmann, Henggeler & Brandeis, 1992). Other attempts have been reported (eg. Wong & Weinberg, 1988) with clinical groups and different techniques (eg. topographic spike mapping, the Dipole Localization Method, etc.). There is still some ambiguity, however, surrounding the precise location of the neural generators, an ambiguity which can obfuscate an attempt to delineate brain function from EEG measures (Nunez, 1981). The generators of the EEG may be situated at some distance from the recording site. Thus, if a particular task elicits greater beta at posterior electrodes, for example, it does not follow that the underlying electrode area is responsible for this shift in activity (see Walter, Etevenon, Pidoux, Tortrat and Guillou, 1984). The greater the spatial resolution provided by the EEG system, however, the greater the accuracy in constructing architectonic maps of cognitive and affective function. The signal, however, may be attenuated by material which intervenes between the recording site and the cortex. The skull, cerebrospinal fluid, inter-cranial tissue, dura mater, skin and hair all contribute to the "smearing" of the signal so that activity recorded from a given site may not be as clear as at the point of generation (Cooper, Winter, Crow & Walter, 1965).

The EEG is also in a constant state of flux. EEG machines normally record fluctuations in brain potentials generated by the post-synaptic neurons of dendrites and measured

from the scalp. The signal, therefore, is not stable or constant but spontaneously alters over time (Lopes da Silva, 1982). Some have characterised this feature of the EEG as chaotic (Freeman, 1991). If EEG is recorded as a subject performs a series of tasks, therefore, it is unwise to record less than 30 seconds of activity for each of eyes open baseline, eyes closed baseline and task performance since there would not be enough information in the record (remembering that this record has not yet been inspected for artefact) to accord it reliability (Etevenon, Samson-Dollfus, Kemali & Perris, 1982). Burgess and Gruzelier (1993), for example, suggest a minimum of 62 seconds which itself may be a conservative estimate if a thoroughly reliable, robust and representative amount of data is required. Others recommend slightly shorter sampling periods (Davidson, 1992), demonstrating good test-retest reliability and internal consistency (Tomarken, Davidson, Wheeler & Kinney, 1993). This minimum would ideally be free of artifact contamination from ocular and muscle sources (see below), factors which tend to reduce the amount of available, useable data to one-half/ two-thirds.

A further factor which may contribute to the complexity of the *interpretation* of the EEG is the influence of artifact. Under normal, and even under optimal, recording conditions, the EEG is prone to contamination from a number of sources- eye movement, muscle movement, respiration, photomyoclonic response (to visual stimulation), tremor and aliasing (a signal containing high frequencies is sampled at too low a rate; this sampling rate ideally should be at least two to three times the high frequency end of the bandpass; signals generated by other equipment are prone to induce aliasing. Aliasing may also result from ambient electrical fields producing a 60Hz alternating current; see Coburn & Moreno, 1988; Kahn, Weiner, Brenner & Coppola, 1988). The most virulent of these contaminants is ocular. The moving eye is a common, notorious generator of low frequency EEG artifact which is visible in the delta and (less so) theta ranges although algorithms may delete contaminated EEG

segments on-line. The rejected periods for Brain Electrical Activity Mapping (see **section 4.4** below) normally include data which have exceeded 95% of the analog/digital range. These rejected files tend to contain evidence of saccades or large eye movements, observable by the application of EOG leads, and normally appear in frontal electrodes or EEG maps. Other, small ocular deflections may, however, be difficult to detect. The conclusion of recent reviews is that methods for eliminating the EOG have been largely disappointing (Elbert, Lutzenberger, Rockstroh and Birbaumer, 1985; Coburn and Moreno, 1988). Muscle artifact generated by restless subjects or tasks requiring motor movement is also a problem and tends to appear in temporal and frontal leads, largely in the beta frequency range. Filtering may, again, remove large potential changes.

#### ***4.4. Brain mapping & EEG.***

The EEG, however, has several practical and psychophysiological advantages over other psychophysiological measures. EEG measures are relatively non-invasive, allowing the subject to be tested with the minimum of discomfort. CNS activity is also recorded fairly directly in real-time. The advantage of such a system is evident when one considers the rapid changes which occur in the Central Nervous System. The EEG is more vulnerable to psychological factors and to stimulus onset than other types of psychophysiological measures such as Galvanic Skin Response (GSR). The unresponsiveness of the GSR to psychological manipulation, is not unsurprising given that it may represent the complete repertoire of subject's response from the sensation and perception of the stimulus to its appraisal and the subject's reaction to it (Naatanen, 1983). Other ANS measures such as heart rate present other difficulties such as the variation in response caused by sinus arrhythmia. The EEG technique, on the other hand, allows the recording of human CNS activity, with no detriment to the subject

while being sensitive to changes in the physical and psychological environment and allowing the observation of possible brain lateralisation of function.

There are also practical, analytic advantages. Artifact may be rejected either on-line or during post-hoc inspection. Modern recording systems employing Fast Fourier Transform algorithms to simplify complex data facilitate interpretation EEG by converting it into bandwidths (with stored numerical representation); gross changes in the amount of EEG band activity generated by a stimulus is thus easily measured by downloading data to a site where statistical analysis can take place. Brain Electrical Activity Mapping also allows the construction of coloured topographical maps from averaged waveband-EEG (the average frame of epoch is usually 2.56 seconds, but may be less depending on the recording system used). In effect, these are a short-hand, visual method of conveying information about activity measured from the scalp (Duffy, McAnulty & Schachter, 1984; Duffy, 1986; Wong, 1991). While indicating possible sites of high and low activity, however, such a system may also be heuristically misleading with stark colour contrasts eventually representing non-significant differences in the final analysis (see Duffy, McAnulty & Schachter, 1984). The general usefulness of these maps in quantifying relationships between psychological variables and electrophysiological activity has been praised and criticised (see Duffy, 1986; Tyler, 1985). It is probably wise to regard them as ornate indicators of possible EEG changes rather than as definitive representations of the electrical activity of the scalp.

#### ***4.5. EEG: statistical considerations.***

In addition to its recording, the design and analysis of EEG data is problematic. Most EEG studies employ spectral analysis to manipulate data although this technique has been challenged (Lorig, 1986). Lorig and his colleagues employ analysis of zero-crossings (period analysis) which determines the duration of the major period of each

EEG waveband and quantifies the number of EEG waves that occur in various frequency bands. Few brain mapping systems will allow such manipulation, however, due to the FFT algorithm. The fact that EEG studies using spectral analysis continue to demonstrate significant EEG changes to psychological, task-based variables, suggests that the mode of analysis is one of preference rather than superiority.

The amount of data accrued in even the simplest EEG study may be considerable. The number of electrodes may exceed 150, there are at least five conventional, analysable wavebands, the number of conditions is often many and, in repeated measures designs, the number of trials can be large. EEG experiments tend to be of a within-subjects repeated measures design which presents its own problems, not only in terms of data accretion but with regards to the violation of the sphericity assumption when performing an analysis of variance (Vasey & Thayer, 1987). The application of an ANOVA rests on several assumptions: normal distribution and homogeneity of variance amongst groups, for example. Although fairly robust in deflecting violations of these assumptions, ANOVA using a repeated measures design also encounters high intercorrelations among the means on which comparisons are based. Assumptions regarding the nature of these correlations are necessary before a p value is declared significant. The problem is elaborated by Vasey & Thayer (1987): "In general, the p values of the F tests are accurate only when the variance-covariance matrix Z can be said to be spherical or circular. This is true if and only if the variance of all the contrasts between repeated measurements which compose the overall comparison of interest (e.g. the within subject main effect) is constant." (p.480). Repeated measures contrasts, however, as already noted, are highly intercorrelated. Furthermore, the closer to each other the two measurements are in time, the higher the correlation. The resulting, uncorrected p value from such an analysis would therefore run the risk of producing Type I errors.

There are methods of circumventing the sphericity problem. The multivariate nature of highly correlated repeated measures suggests the use of MANOVA since this does not need to meet the assumption of sphericity. This approach is also quite robust to violations of normality. The remaining difficulty would be to use a subject sample compatible with a MANOVA approach, i.e.  $n = k + 20$ , where  $k$  is the number of conditions; fewer subjects than this might deflate the power of the test. The second, most commonly used approach, especially in psychophysiological investigations where the number of subjects required to fulfil the MANOVA criteria would be considerable, is to protect against sphericity by adjusting the degrees of freedom of the univariate tests (usually by multiplication with "epsilon correction") to compensate for the positive bias (Box, 1954; Geisser & Greenhouse, 1958; Huynh & Feldt, 1970). Since most statistical packages feature either Huynh-Feldt or G-G corrections for repeated measures design, most analyses with this design may circumvent the Type I error.

A second, major problem, as mentioned above, is p-inflation. The EEG is a notorious producer of large amounts of information. The number of ANOVAs and post-hoc tests which one could conceivably perform on the data is considerable. The likelihood that  $p$  will be inflated- leading to the rejection of the null hypothesis even though it is valid-is possible. Thus one in twenty comparisons may lead to the declaration of a significant result when it is not. For this reason some authors have suggested that the use of inferential statistics in EEG analysis may be more allusive than prescriptive: The  $p$  values provide "hints" as to what factors are responsible for the observed changes and as such are descriptive (Rappelsberger & Petsche, 1988). There are also methods of overcoming this problem: Bonferroni probabilities are probably one of the more conservative methods of post-hoc testing of effects and take into account  $p$  inflation. This approach divides the conventionally accepted level of significance (0.05) by the

total number of comparisons required. This new significance level is quite strict. If there are three comparisons, the tables suggest a  $p$  value of 0.01 (rounded). Thus any significant effect which exceeds this level might be legitimately said to exceed 0.05. A less restricted and more flexible approach is provided by Tukey's HSD. This allows for multiple comparisons by comparing values of  $Q$  obtained from the data with critical values of  $Q$ . Either approach may be used, but for large numbers of unplanned, pairwise tests, with a 2-way ANOVA, Tukey's appears to be the more desirable. For a three-way ANOVA, however, it may be necessary to calculate  $t$ -tests between pairs of means and then invoke the Bonferroni approach. In this way, any spuriously significant results will be declared non-significant. There is a danger, however, that such a conservative  $p$  value will encourage Type 2 errors. In this instance, the expectation of a meaningful statistic must be weighed against need to exercise caution.

When encountering  $p$ -inflation and Type 1 errors, it may be meaningful to consider patterns of results. Therefore, if a number of pairwise comparisons are declared significant, and are significantly meaningful to the hypothesis tested, then the pattern may be reflective of true effects. Some authors would argue that the use of these inferential statistics is not particularly helpful to the analysis and interpretation of EEG data. This, however, is the extreme end of the spectrum, the other end of which would declare any result within the significance level of 0.05 meaningful. Inferential statistics can be informative in the analysis of EEG as long as interpretations are made cautiously and the necessary corrections made to accommodate the problems encountered. Although this problem in EEG is virtually intractable, the conservative measures taken here ensure that the data must obey strict criterion before they are declared significant and, ergo, meaningful. Practical consideration of EEG data analysis is provided in **Chapters 5-7.**

**4.6. Event-Related Potentials and their potential relation to information processing.**

More pronounced effects on brain electrophysiology are obtained with repeated psychological stimulation. Repeatedly presented visual or auditory stimuli, such as flashes and tones, generate an averaged response which stands in isolation from background EEG (Donchin, Ritter & McCallum, 1978). Exogenous potentials, such as those generated by simple external sensory stimuli, can be clearly obtained under optimal recording conditions. Endogenous potentials generated by subjective responses to stimuli, may also be clearly obtained but their precise function and definition is, unlike the simple stimulus-response nature of the sensory potential, unclear (Ritter, Vaughan & Simson, 1984). Event-related potentials (or ERPs), however, may reflect not only complex cognitive processes but also a complex interaction with other internal and external variables, odour and food ingestion among them (Lorig *et al.*, 1991; Geisler & Polich, 1992 a, b).

The course of the "spontaneous" EEG is erratic. Although shifts in potential can be measured in each respective waveband and to a given psychological variable, the task is not helped by an enormity of background "noise", the chaotic baggage carried by the brain. Averaging EEG responses over a series of trials assists in reducing this background noise and highlighting the foreground effect. The assumption is that brain activity is time-locked to some impinging stimulus (hence, event-related). Andreassi (1989) exemplifies this thus: If a single ERP is 5uV and background EEG is 20uV, the EP will increase as a function of N samples (in this example, 100) whereas background EEG will increase as a function of N square root,

$$\frac{\text{EP amp (N)}}{\text{EEG amp (square root of N)}} = \frac{5\mu\text{V (100)}}{10\mu\text{V (10)}} = \frac{500}{200} = 2.50 \text{ (the EP)}$$

In this example, the EP is two and a half times as large as the background EEG. Sensory stimulation can be measured by this technique relatively easily. Exposure to visual stimuli produce reliable ERPs at the occipital pole (the striate cortex), somatosensory stimuli at the motor strip and so on. The generators for the various sensory-related potentials may vary in site. Signal generators for EPs produced by auditory stimuli have been found at the auditory cortex in the temporal lobe (Vaughan & Arezzo, 1988), those for somatosensory and visual EPs at the post-central gyrus and the primary visual cortex, respectively (Vaughan & Arezzo, 1988).

#### **4.7. The P300.**

Where event-related potentials become of increasing psychological interest is that point at which they may be assumed to reflect information-processing. The "endogenous" P300 component of the evoked potential is a late positive-going wave occurring at around 300 milliseconds after stimulus onset. It is commonly referred to as an information-processing or decision-making wave since it commonly appears as a result of a subject's engagement in a task requiring discrimination of some kind (Sutton, Braren, Zubin & John, 1965; Donchin, Ritter & McCallum, 1978; Donchin & Coles, 1988). One of the most inductive task appears to be the auditory oddball task in which individuals count the number of low tones in a series of high and low tones as subjects' brain electrical activity is measured (Sutton *et al.*, 1965). Electrical potentials to each of the stimuli are recorded and the total for each pitch is averaged. There are always fewer low than high tones (usually in the ratio 1:4). Ordinarily, the resulting EPs appear at 100 and 200 milliseconds after stimulus onset to each type of tone. The N100 is assumed to reflect sensory-information processing. Its positive-going return wave, the P200, is poorly studied but may be reflective of the distribution of attentional resources. It has been suggested that these two components co-vary and sometimes overlap although there is evidence for their separation (Näätänen & Picton, 1987).

The precise meaning and function of the P300 is still uncertain (see commentaries, Donchin & Coles, 1988). It is modality non-specific since a visual or verbal oddball task may elicit a P300. It is commonly associated with cognitive activity and more than likely reflects some form of information-processing. Other variables affecting its appearance and amplitude include signal probability, attention, uncertainty reduction and stimulus relevance. Stimuli which "resolve the subject's uncertainty" have been found to elicit the P300 (Sutton *et al*, 1965). Others report that since the P300 is elicited when signals were detected but not when undetected, this EP is implicated in the evaluation of stimulus significance (Ritter & Vaughan, 1969). The function of "context updating" has also been ascribed to the P300 (Pribram & McGuinness, 1975) as has the indexing of the "operation of adaptive brain systems" (Hillyard & Picton, 1979). Others recognise the wave as a reflection of the subject's information processing. For example, subject's asked to guess whether a stimulus would consist of 1 or two clicks generate a large P300 to the second clicks only (Donchin *et al*, 1983). (Johnson (1986) has, in fact, suggested a model of P300 function representing three-dimensions: subjective probability, stimulus meaning and information transmission, any one of which may be sufficient but not necessary to elicit a P300).

One important factor in the generation of the P300 is attention. When attention is divided between a primary task (manual tracking) and a secondary task (counting target tones), the P300 amplitude decreases (Israel, Chesney, Wicken & Donchin, 1980). This has been interpreted in terms of a multiple resource theory which suggests that separate resource pools correspond to different modalities (Wickens, 1984). As a greater decline in the P300 was not observed as a result of increasing task difficulty, the theory suggests that the difficulty factor depletes resources which are not used by the P300. When task difficulty is increased (monitoring of shapes was coupled with a

counting task) the P300 to tone-counting decreases, which suggests that the number of added shapes depletes "perceptual-level" resources used for counting. If this is the case, then practising a primary task to the point of automaticity should result in a relatively unchanged P300.

The P300 to the infrequent stimuli is negligible when subjects are not instructed to discriminate between tones (Polich, 1986). P300 amplitude is smaller during finger tapping than in silent counting paradigms (Polich, 1987). Latency remains relatively unaffected by attention and probability although longer latencies have been reported to silent counting than to finger tapping or button pressing. Longer latencies are also found with ageing (Brown, Marsh & LaRue, 1983; Polich, Howard & Starr, 1985; O'Donnell, Friedman, Swearer & Drachman, 1992). Habituation to signals (by increasing stimulus probability) reduces the amplitude of the P300 but if the pitch of the tenth stimulus, for example, is changed, then a marked increase in P300 is generated (dishabituation) (Polich, 1989). Dishabituation may also be evidenced when deviant, task-irrelevant events are embedded in a series of attended stimuli (Courchesne, Courchesne & Hillyard, 1978) when irrelevant events are highly intrusive (Squires, Donchin, Herning & McCarthy, 1977) or when the distinction between relevant and irrelevant channels is blurred (Hansen & Hillyard, 1983). It should be noted, however, that Pritchard, Brandt, Shappell, O'Dell & Barratt (1986) reported no habituation of the P300 over time.

The effect of extraneous variables on the ERP has recently been considered in a number of investigations. Dual-task paradigms where an external task is performed in tandem with the primary counting task generally results, as noted earlier, in divided attention and a reduced P300. Other factors such as personality, diurnal cycle, food consumption and olfactory perception have recently been considered influential in

modulating this component. Food consumption and olfactory perception, in particular, are of especial interest since, as noted in **Chapter 3**, improvements and decrements in cognitive performance has been found to be associated with both meal ingestion and content and exposure to odour.

#### *4.8. Changes in evoked potentials: food consumption or diurnal variation?*

Subjects tested early in the early afternoon have been found to generate larger EP amplitudes than when tested at mid-morning (Broughton, Aguirre and Dunham, 1988). The finding suggested that the subjects' diurnal cycle was influential in producing an alteration in the amplitude of the EP. This specific time-of-day effect, however, has not only been difficult to replicate but is often contradicted. For example, higher amplitudes have been found in the morning (Wesenstein, Badia & Harsh, 1990), or found in the evening than morning (Browman, 1979) or have been unaltered by the time-of-day (Dalbokova & Kolev, 1989; Geisler & Polich, 1990). Studies examining the interaction between time-of-day, P300 amplitude and diurnal type (morning-preference vs. evening-preference) have reported significant and consistent AM/PM differences for auditory N100 and P200 responses (Kerkhof, 1980; Kerkhof, Korving, Willemse-Geest & Rietveld, 1980) while showing no diurnal variation in the P300 (P450). The picture is, therefore, highly ambiguous.

One possible explanation for the inconsistency in studies of diurnal ERP may lie in the possibility that there are factors, excluding diurnal cycles, which are responsible for the inter-session alteration in the ERP. Subjects who had eaten three hours of being tested in an auditory oddball experiment, for example, have been found to show significantly larger P300 amplitude than subjects who had not eaten for six hours (Geisler & Polich, 1992a). The target N100 or P200 were relatively unaffected by recency of food

consumption. In a second experiment, subjects were tested fourteen hours after fasting, five minutes after eating a lunch of peanut butter, jelly sandwich, apple and a fruit drink, and thirty minutes post-prandially. Target P300 increased significantly after consumption but decreased at the third measurement (Latency was relatively unaffected in both studies). Subjects receiving a recent intake of food also showed better memory recall for words after ingestion and a strong short-term memory recency effect, a finding which the authors argue reflects the appearance of the P300- a general increase followed by gradual decrease. This is an interesting finding in view of P300's general-purpose manifestation as a memory-updating component. In a subsequent investigation of diurnal preference and recency of intake, larger but non-significant P300 amplitude was observed in the food group, but a significant time-of-day by diurnal type interaction was reported with morning-preference subjects who had not been recently fed producing greater P300 amplitude in the morning than in the afternoon (Geisler & Polich, 1992b). Evening-preference subjects demonstrated a similar effect but with larger P300 in the evening. Much weaker preference-activity effects were evidenced when subjects had eaten recently. There was no effect of lunch on N100 or P200 amplitude although significant interactions were observed with the latency data: the morning-preference/no-food group produced shorter N100 latencies than the evening-preference/no-food group but the opposite effect was found with the food groups. P200 latency was also shorter in evening-preference subjects.

#### *4.9. ERPs and food analogues.*

On the basis of the foregoing evidence, it is arguable that recency of food consumption has the ability to modulate ERP behaviour. Similar findings have been reported in studies using food analogues. Bolus injections of the neuroactive peptide hormone cholecystokinin (CCK) have been found to affect EP components, specifically the N1-P2 complex. CCK is known to exert metabolic effects, induces satiation in animals and

humans (Silver & Morley, 1991) and is present in lower levels in sufferers of bulimia nervosa than in healthy controls (Lydiard, Brewerton, Fossey, Laraia, Stuart, Beinfeld & Ballenger, 1993). A 0.5 ug bolus injection of ceruletide, a cholecystokinin analog, has been found to diminish the amplitude of the auditory P200 in attentive, unstarved subjects (Pietrowsky, Fem, Er, Bathelt & Born, 1990). Other authors report a reduced auditory N1-P2 amplitude following low doses of CCK but an increased amplitude following administration of high doses during distraction by the aroma of cooking food and the noise of food preparation (Stacher, Bauer & Steinringer, 1979). A diminution of the auditory P200, but not N100, following 0.5 ug ceruletide infusion, but not after bolus injection using a within-subject comparisons design has also been reported (Pietrowsky, Schiemann, Fehm & Born, 1993). The Stacher study is of particular interest since it is the first study of its kind to examine the effects of olfactory stimulation on ERPs and is one of the earliest investigations of pre-and post-prandial olfactory EEG.

In this study, 16 subjects were placed of four treatment conditions: 180 ml/30 min. of either saline, 0.6, 3.0 or 6.0 U CCK/kg body weight by intravenous infusion, and their ERPs were recorded. During the penultimate fifteen minutes of the testing period, subjects with eyes-closed were exposed to the smells and the sounds of the preparation of a meal: bread and butter, cut fresh chives, butter melting in a pan, and eggs and bacon frying. The aim of this final procedure was to "stimulate the subject's appetite" as ERPs and EEG were recorded. Subjects in the saline group reported increases in feelings of hunger and voraciousness when exposed to the foods but the increases in the CCK groups were significantly smaller with increasing dosage. A linear dose-relationship response was observed in the AEP data with N1-P2 showing marked diminution with increasing dosage during exposure to the food. During the baseline saline vs. CCK period, there was no significant difference between groups, however.

What is more, EEG alpha increased in saline subjects but decreased with increasing doses of CCK. Theta decreased during infusion of saline and exposure to food preparation but increased with increases in CCK. Beta activity also increased with increasing dose of CCK with the greatest increase during CCK administration (compared with the food preparation period). The authors conclude that,

*"When attention is attracted by the food-related stimuli and shifts away from the auditory stimuli presented, the number of neuronal units recruited by such stimuli diminishes and a decrease in AEP amplitude results. When, with increasing dose of CCK, the food-related stimuli become less powerful in attracting the subject's attention, more attention is attracted towards the auditory stimuli and consequently AEP amplitude increases despite the concomitant general deactivation." (p.331).*

Pietrowsky *et al* (1989) interpret a similar lack of N200 attenuation following CCK and exposure to food cues in their study as an indication of the diminished ability of the food cues to cause distraction in their subjects.

The diminution of the AEP following distraction or lack of attention is well-documented. The reduction in P300 amplitude appears, as mentioned above, to be especially sensitive to external variables unassociated with the task being performed. An exploration of ERP response during stimulation by olfactory food cues, before and after the ingestion of a "natural" meal i.e. cooked food which is naturally ingested has not been undertaken. The results from Stacher *et al* (1979) and Pietrowsky *et al* (1989) encourage the view that relevant olfactory cues coupled with the ingestion of satiating agents produce marked and significant effects on human brain electrophysiology.

Further evidence to suggest the ability of odour to alter the course of CNS activity is assessed below.

#### *4.10. EEG & odour: methodological considerations.*

Experimental interest in observing the EEG effects of olfactory stimulation had, until recently, focused on studies using animals. Considerable evidence has accumulated since Adrian first placed electrodes in the olfactory bulbs of hedgehogs (Adrian, 1942), suggesting ways in which invasive and non-invasive exposure to odour may affect sub-cortical structures (especially the olfactory bulb) and cerebral cortex (see, e.g., Freeman, 1991; Davis & Eichenbaum, 1992).

Moncrieff's (1962) early human study of EEG response to odour using rudimentary EEG recording techniques found that almost all the presented odours (including essential oils, synthetic oils and unpleasant-smelling chemicals) produced a general reduction in alpha activity (as measured by eight, bilaterally-placed electrodes) in five subjects (ylang ylang had no observable effect on the EEG). Similar desynchronisation had been noted four years earlier (Bushteva, Polezlaev & Semenenko, 1958), although electrode sites were not specified. The findings suggested that odour was capable of precipitating CNS activation (as reflected in low levels of alpha).

Since Moncrieff's (1962) experiment, subsequent investigations of human EEG activity during olfactory perception have been sparse. This scenario is unlike that of the study of olfactory evoked potentials (OEP) and chemosensory evoked potentials, which since Allison and Goff (1967)'s early investigations has burgeoned (Plattig, 1989; Kobal & Hummel, 1991). The momentum behind OEP studies lies in the ability to investigate the effects of odour on brain electrophysiology directly under optimum conditions. Modern olfactometry delivers the odour, or chemical or gas, at precise flow rates and

at controlled intensities as EEG is monitored. By averaging trials, an EP is created. The "spontaneous" EEG, on the other hand, teases out any effects an odour may have on a fairly naturally behaving human being. **Table 4.1.** summarises the main findings from all the principal papers published on human EEG response to odour. It is evident from this inventory that the number of studies investigating these responses continues to be remarkably small. The impetus behind the recent increase in the number of studies published appears to stem largely from the recent drive to examine the claims of aromatherapy (Lorig & Schwartz, 1988) and the evidence provided by olfactory psychology (hence the predominant use of "synthetic" odours and essential oils in these studies). The claim that odour may affect mood, cognition and other psychological factors has precipitated much of the psychophysiological investigations of odour perception in the past decade (Lorig & Schwartz, 1988; Lorig & Roberts, 1991; Klemm, Lutes, Hendrix & Warrenberg, 1992; Van Toller, Behan, Howells, Kendall-Reed & Richardson, 1993; Martin, 1992; 1993).

Recent, methodologically improved (in comparison to the crude designs of Moncrieff) and expanded investigations have produced largely inconsistent results, a finding which is probably attributable to the number and kind of odours used, the recording and analysis techniques employed, the period of EEG selected for analysis, and subject selection. One study, for example, has reported differences in the amount of alpha activity over right and left hemispheres (although the specific direction of the differences are not reported) and greater theta activity using fine fragrances as stimuli and four electrodes as recording measures (Lorig & Schwartz, 1988). In a separate experiment using three different odours and four electrodes, decreases in activity were found in the theta frequency. Others, using eight different odours and nineteen electrodes, report no alteration in alpha but selective increases in theta (Klemm *et al.*, 1992). In the former studies (Lorig & Schwartz, 1988), greater theta to fragrance was

4.1. Table summarising published studies of human response to olfactory stimulation using EEG/ERP measures.

Author/year	Subjects	EEG/ERP	Odour and Concentration	Electrodes	Bands	Exposure Period	Effects of odour
Bushetva et al (1958)	8 (female)	EEG	Hydrogen sulphide (2.4-3 ug/m <sup>3</sup> 1.5-8 ug/m <sup>3</sup> )	Unknown	alpha	Unknown	Desynchronization of alpha at 9ug/m <sup>3</sup>
Moncrieff (1962)	a) 1 (male)	EEG	floral perfume, night-scented stock, n-butyl alcohol, pyridine, synthetic musk, lavender, alpha-ionone, methyl anthranilate, fresh chives, silylyl acetate, cinnamon, citral, patchouli oil, ylang-ylang, lemon-grass-oil	8 (4 left hem; 4 right hem)	alpha	6/7 secs per odour	General reduction/depression of alpha
	b) 4 (male)	EEG	8 floral perfumes, lemongrass, n-butyl alcohol, pyridine, alpha-ionone, carbon disulphide, ammonium sulphide, musk ambrette	as Expt a)	alpha	? as a)?	General alpha suppression/elimination but not for ylang ylang.
Stacher et al (1979)	8 (male) 8 (female)	AERP & EEG	smell & sound of chives being cut and placed on bread & butter, frying butter, eggs & bacon	CZ	theta alpha beta	15 mins.	(i) theta decrease in groups receiving saline; increase in CCK infusion Ss. (ii) N1-P2 amp.

diminished in  
saline & small dose  
CCK Ss.

Branell et al (1980)	17	EEG	acetylaldehyde, cinnamaldehyde, eugenol, linalool	CZ, PZ, FZ	Power spectra	3 times during 45 secs.	80% of EEG spectra correlated with 'unpleasant' odour rating; 60% with 'pleasant'.
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Wernitz et al (1983)	43	EEG	Room-air	P3, P4, C3, C4, T5, T6, O1, O2, CZ	delta, theta, alpha, beta	40-215 min recording period; Mean-90 mins.	No significant changes in hemispheric dom- inance unless accom- panied by transition in nasal dominance; of 15 subjects not showing transition, 10 showed correlation of dominant nostril with greater EEG amplitude in the contralateral hem.
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Lorig & Schwartz (1988)	a) 9 (male) 4 (female)	EEG	spiced apple, eucalyptus (60% in DEP) and lavender (in DEP)	F7, F8, T5, T6	theta, alpha	1 min	(i) no effect for alpha; (ii) reduced theta to odour esp. in right frontal & left posterior -SA produced less theta than lavender (iii) no EEG effect of hedonics/intensity- (iv) SA & E associated with less anxiety & tension than lavender.
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	b) 6 (male) 4 (female)	EEG	5 fine fragrances (floral) to a 5% solution in distilled H <sub>2</sub> O	as a)	as a)	as a)	(i) differences in the amount of alpha activity over L&R hemis. (ii) most odours produced greater left theta (except perf. 4).
Lorig et al (1988)	10 (male) 10 (female)	EEG	Room air inhaled through (i) mouth or (ii) nose	F7, F8, T5, T6	theta, alpha, beta	2 secs of EEG following each inhal & exhal. analysed	(i) theta increased in right hem during exhal; (ii) alpha lower in L hem during nose inhal; (iii) beta showed greatest ant/post diversity during nasal inhal.
Torii et al (1988)	4 (perfumers) 3 (male grads)	CNV	20 essential oils	FZ, CZ, PZ, F3, F4, C3, C4, P3, P4	-----	1-3 secs before each trial	(i) increased CNV at F3/F4 and C3/C4 to jasmine; (ii) no effect on heart rate/RT.
Pietrowsky et al (1989)	7 (male) 6 (female)	AERP (oddball)	smell and sound of frying butter, onion, eggs, bacon & spices.	FZ, CZ, PZ	-----	20 mins.	Decrease in N2 amp in Ss receiving saline soln.
Lorig et al (1990)	8 (male) 8 (female)	EEG	lavender oil, spiced apple at low, med. and high concs.	F7, F8, T5, T6	theta, alpha, beta	15 secs.	(i) theta differences as function of conc. Greatest between low, and med. More left posterior for both lav. concs.

Badia et al (1990)	4 (male) 6 (female)	EEG	Peppermint	C3, C4, O1 O2	-----	Stage 2 & REM sleep	(ii) Anterior/posterior changes in beta as function of conc.  (i) greater switch closures made during odour exposure: (ii) % of EEG "speaking" greater to odour.
Long & Roberts (1990)	16 (male) 2 (female)	CNV	jasmine, lavender, galbanum and JLG mixture (all iso-intense in DEP)	F7, F8, T3, T4, T5, T6, Fz, Cz, Pz	-----	4 secs., following prime.	(i) differences in lateral distribution of CNV to low-conc odours: (ii) the greater the intensity of jasmine the higher the frontal amplitude.
Lorig et al (1991)	a) 12  b) 5 (male) 3 (female)	EEG  AERP	galaxohide (10 ml, 80%, 20% and 5%)  As a)	F7, F8, T3, T4, T5, T6, Cz, Pz  As a)	alpha & Factor 1 (5-8Hz)  -----	10 secs  During each trial	Alpha lower during undetected galaxohide.  (i) no odour effects on N100. (ii) P300 to rare stimuli increased as a function of odour: (iii) P200 increase over midline with lowest conc.
Klamm et al (1992)	16 (female)	EEG	birch tar (10% in DEP), galbanum (10%), heliotropine (25%), jasmine	FP1, FP2, F3, F4, F7, F8, C3, C4, T3, T4, T5,	delta, theta, alpha, beta	2 mins.	(i) no effect on alpha, beta or delta: (ii) increased theta for birch tar, jasmine.

(100%), lavender  
(100%), lemon  
(100%), peppermint  
(10%), room-air

T6, P3, P4  
01, 02, FZ  
CZ, FZ

lavender and lemon:  
(iii) Some unpl.  
odours, eg. tar &  
galbanum had

opposite effects: ditto  
for pl. odours: p.p.  
decreased; jas.  
and lem. increased).

Kendat-Reed & Van Toller (1992)

8 (3 mths old)  
chicken dinner,  
chocolate pudding,  
beef dinner, fish in  
tomato sauce (25g)

EEG

28

delta

unknown

C3 amp. increase  
to chicken and fish.  
CZ to beef, CP2 to  
chicken and fish.

Van Toller et al (1993)

9 (male)  
6 (female)  
5-alpha-androstan-3-  
one, Baingadol, White  
Sapphire, indole,  
linalyl acetate and  
cucalyptus oil &  
ammonia.

EEG

28

alpha

10 secs.

Alpha increases  
in some electrodes:  
T3, T4, FTCl and  
FZ significantly  
correlated with odour  
pleasantness, strength  
and familiarity.

**KEY:**

EEG-electroencephalogram  
ERP-event related potential  
AERP-auditory event related potential  
CNV-contingent negative variation  
CCK-cholecystokinin

evident in the left hemisphere whereas theta was reduced to the other odours especially in right frontal and left posterior areas. Specific inter-odour differences were also found with spiced apple producing less theta than lavender. In the latter study (Klemm *et al*, 1992), birch tar, jasmine, lavender and lemon were associated with increases in theta. Thus, although recent studies have employed much more sophisticated EEG technologies and presentation techniques, there continues to be a persistent variability amongst these findings.

Most of these studies use adult subjects in conditions of optimum relaxation (eyes closed, seated) and employ exposure periods lasting from 6/7 seconds per odour (Moncrieff, 1962) to 2 minutes (Klemm *et al*, 1992). The time consideration in recording responses to odour is important. If habituation to an odour occurs too quickly (the odour is not suprathreshold), then it is possible that the brain does not register such "subliminal" stimulation. Two studies, however, have demonstrated differences in the amount of alpha (Lorig, Huffman, DeMartino & DeMarco, 1991) and theta (Lorig, Herman Schwartz & Cain, 1990) as a result of exposure to undetected galaxolide, and low vs. medium concentrations of spiced apple and lavender oil, respectively. In another study, greater EEG speeding was reported to peppermint odour in sleeping subjects (Badia, Wesenstein, Cammers, Culpepper & Harsh, 1990) although the procedure employed by the experimenters whereby the subjects are woken up if they did not stir, are told that the odour was present and then requested to resume their sleep raises some doubt as to the validity of the procedure.

The difficulty then arises as to whether the brain, after sensing the odour for the first time, then recovers from its initial arousal following stimulation and continues behaving as chaotically as before. A form of cerebral habituation may be in evidence if an odour is presented for too long a time. Associated with this difficulty, however, is the amount of EEG that is necessary for any statistical analysis to show reliable effects. As

noted in **section 4.3**, authors are fairly flexible concerning the minimum amount of artifact-free data that is required in order to make the EEG sample "representative" but a minimum of sixty seconds would appear to be advisable (Burgess and Gruzelier, 1993). With systems employing algorithms which may correct for eye movement, the necessity of recording a given set of frames is only governed by the need to collect a reasonable sample of data. When no such algorithms are available, however, the amount of data has to be collected carefully, bearing in mind that contaminated records will be discarded and will therefore reduce the amount of useable and analysable data. Thus Van Toller *et al* (1993) use samples of a maximum of ten seconds with no apparent eye-corrections. It is imaginable that a considerable amount of this data is corrupted which leaves their total number of used frames unknown and the interpretation of their results questionable.

The method of inhalation has also been reported to affect the pattern of the EEG. Nasal inhalation has been found to produce greater anterior/posterior diversity in beta than mouth inhalation. This form of inhalation also appears to reduce left hemisphere alpha (Lorig, Schwartz, Herman & Lane, 1988). Lehmann and Knauss (1976) also report increased desynchrony as a result of inhalation of room-air while others have demonstrated a correlation between increased EEG amplitude in one hemisphere and the contralateral nostril during inhalation of room-air (Werntz, Bickford, Bloom and Shannahoff-Khalsa, 1983). The respiratory mode of the subjects in EEG experiments is, therefore, important.

#### ***4.11. Event-related potentials & olfaction.***

The influence of odour on components of ERP is more poorly studied than its influence on EEG. Results in this domain, however, suggest that exposure to odour also exerts electrophysiological effects. An increase in the Contingent Negative Variation at four

electrodes to the odour of jasmine has been reported (Torii, Fukada, Kanemoto, Miyachi, Hamauzu & Kawasaki, 1988). This study has been partly replicated using slightly different subject samples: Torii et al employed both Japanese professional perfumers *and* male students as subjects although this study has been erroneously criticised for using perfumers only (Lorig, 1989). One other study has employed American male and female students (Lorig & Roberts, 1990). In this latter study differences in the lateral distribution of the CNV were observed to the low concentration odours.

One other study has reported explicit odour effects on ERPs. Increases in the P300 have been found with increasing concentration of galaxolide in an auditory oddball task but reported no effects on target or standard N100 (Lorig *et al*, 1991). P200 increased to the lowest concentration odour. Latencies for this study were not reported. Whether this was due to non-significant findings or a failure to consider latency data is unclear. Evidence elsewhere (Lorig, Mayer, Moore & Warrenburg, 1993) would suggest the former. The most curious finding from this study is the increase in P300 following increases in odour strength and the authors' explanation for the finding. The authors argue at one point that increased P300 amplitude is "generally associated with increased accuracy of performance and more complete cognitive processing of stimuli" citing Donchin, Rutter & Coles (1978) as a reference. The "complete cognitive processing" explanation would be more plausible if the statement was modified to: "increased attention to the stimulus is associated with increases in P300 amplitude", for which there is some evidence (see Section 4.7.). However, a contrary explanation is stated in the discussion with distraction cited as a variable resulting in the increased P200 and P300. In a later review, it is reported that the "data strongly suggest that the presence of Galaxolide, even in undetected concentrations, distracted subjects and resulted in the underestimation of the likelihood of the infrequent tones" (Lorig, 1992).

As a result, P300 amplitude was found to increase significantly. This, as studies of P300 amplitude determinants demonstrate, is highly unlikely. Distraction from target tasks used in ERP investigations normally results in *decreases* in target P300 amplitude, not increases. This distraction-related increase in P300, however, is attributed to the overlapping of P200 and P300 components. Whatever influenced the amplitudes of both P200 and P300 in this experiment, however, it is unlikely to be distraction. If one were to suggest an alternative hypothesis one might argue that attention to the odour even at the lowest concentration may have enhanced attention to the task at hand. Furthermore, it is arguable, although there is no evidence provided by Lorig *et al* (1991), that psychometric properties may have played some part in the subjects' reaction to the odour during task performance (this is discussed at length in **section 4.14**).

#### **4.12. Food odour, the EEG & the ERP.**

The majority of EEG studies using odour as a stimulus has employed the odours of essential or synthetic oils. A small number of studies, however, has investigated the effects of food odour on EEG and ERP, a stimulus which one would assume would have considerably more "relevance" to the perceiving organism. One of the first implicit studies of this kind was undertaken by Stacher, Bauer & Steinringer (1979) who found decreases in theta activity in subjects fed with saline and exposed to the sounds and smells of food being prepared and cooked but increases in those subjects receiving CCK (cholecystokinin -see **section 4.9** for details). Decreasing alpha and increasing beta were also observed with increasing doses of CCK but it is unclear whether these changes accompanied exposure to the food stimuli or were simply the isolated effects of the different ingestive agents. The N1-P2 complex of the ERP was also reported to be diminished in subjects receiving saline and exposed to the food stimuli as well as in subjects receiving small doses of CCK. These results contrasted

with those from subjects receiving large amounts of CCK who showed an increase in amplitude. The aim of this experiment was not concerned with odour effects *per se* but with the effects of combining various ingestive factors (saline, CCK) with other related variables (sound/smell of food). Yet they provide the first indication that food odour affects CNS activity, even if that activity may also be affected by the type of material ingested and the medley of food-related sensory information it responded to.

Pietrowsky *et al* (1989) found similar decreases in EP amplitude in subjects completing an auditory oddball task after receiving saline and during stimulation by the smell and sound of food being prepared and cooked. One obvious feature which does not allow any definitive statement regarding the effects of olfactory stimulation on these electrophysiological measures is the combination of the noise with the smell. Furthermore, that EP changes were found between groups receiving different ingestive agents (but not "normal" meals) suggests an experiment in which subjects are not only allowed to eat natural meals but also receive stimulation by olfactory stimuli alone. If CCK exerts these effects in tandem with the sound and smell of food cooking, it is arguable that food eaten to fullness will exert even more pronounced effects when olfactory stimuli are presented without other sensory involvement.

As noted earlier, Pietrowsky *et al* explain their findings by suggesting that "hungry" subjects (i.e. saline/ low doses of CCK subjects) paid greater attention to the food stimuli, hence the reduction in amplitude. Their attention was distracted by their internal physiological state. Those having received high doses of CCK (and reporting less hunger and fullness) could thus complete the oddball task with little distraction. This is an attractive hypothesis. Ray & Cole (1985) report a series of results which suggest the differentiation of the amount of alpha and beta activity on the basis of the types of task component administered: beta changes reflected cognitive processing;

alpha, attentional demands. A recent study has reported that during the alpha state, N1 and P2 amplitudes were higher during a passive listening tune but not when discrimination between two tones was required. If greater alpha activity is assumed to reflect attentional processes this would suggest that less power in this band is an indication of, amongst other factors, cognitive engagement as opposed to simple attentional demands. In Stacher *et al's* study, an increase in EP amplitude and a decrease in alpha activity was noted with increasing doses of CCK but a slight increase in alpha was observed in subjects receiving saline. Subjects receiving high doses of CCK also showed an increase in beta activity (saline subjects did not) which was most marked during the period prior to exposure to the food stimuli.

Further evidence of the effects of food odour on the EEG is not plentiful. In one study, the EEG delta at three electrodes recorded from 8 week old babies during exposure to the odours of chicken dinner, chocolate pudding, beef dinner and fish in tomato sauce, appeared particularly susceptible to some odours (Kendal-Reed & Van Toller, 1992). Increases in amplitude were found to chicken, fish and beef but not the tomato. The study did not, however, appear to control for intake and other wavebands, for methodological reasons, were not analysed.

Lorig and Schwartz (1988) used what might be described as food odours (spiced apple and eucalyptus) in an early study, reporting that spiced apple produced less theta activity in the right frontal and left posterior regions than did lavender and that both "food" odours were associated with less anxiety and tension than lavender. These findings are associated with the use of food imagery in traditional anxiety management techniques and perhaps suggest a role for the theta band in affect although the evidence presented in this study is highly circumstantial. One study has reported increased theta in the right hemisphere during sexual orgasm (Cohen, Rosen & Goldstein, 1976) but it

would appear that the greatest changes in EEG as a result of different affective reactions lies in the alpha band. This relationship between alpha and affect is discussed in **section 4.14**.

#### *4.13. EEG & food odour: cognitive mediation?*

It is arguable that the response of the EEG to some odours, specifically food odours, may be the result of cognitive mediation and not the direct result of the odour's sensory or psychometric properties. Lorig & Schwartz (1988-89) report that relaxation (thoughts and feelings of heaviness) and imagery of a favourite dessert produced a greater amount of theta and a Factor 1 band at the right posterior electrode than did other cognitively based tasks. Factor 1 activity was significantly greater for dessert and relaxation tasks than for the maths tasks (subtraction). In the right frontal region, dessert imagery and concentration on the word "one" produced more Factor 1 activity than did the maths tasks. Relaxation produced more Factor 1 than subtracting threes. Surprisingly the authors associate this increase in Factor 1 with previous reports of decreased tension and alertness in an earlier abstract (Lorig & Schwartz, 1987). This study, however, reported fully as Lorig and Schwartz (1988) does not include the factor-analysed Factor 1 but alpha. The frequency for Factor 1 has been described as 5.7-8 Hz for left and right frontal electrodes by Lorig and Schwartz (1989); alpha, however, has a much larger range of 8-13 Hz. There is a marked difference, therefore, between the two bands. They cannot be considered interchangeable.

The authors also state that since exposure to food odour and the imagery of food are not of equivalent psychological status (see earlier Gevins critique, **section 4.2.**), the two may not be studied and compared. This is arguable but since such an exploration has not been undertaken, it is premature to disregard such an experiment entirely. One could argue that the tasks used in the experiment were also not of equivalent status

(active counting with possible subvocalisation vs simply feeling heavy, for example). The trigeminal effects of food odour could easily be circumvented with the use of "olfactory" odours such as vanillin for sweet stimuli and the use of hot water as a control stimulus to compare with the presentation of hot foods (cf. experiment three, this volume). Apart from the limited data collected (significant results were apparent in only two out of four electrodes), practical aspects of the study also raise doubts about the reliability of the findings. The first is the recording period. Three ten second epochs are described as being collected for each of the tasks undertaken, with no baseline measure recorded. Since artifact-reduction measures are not described in the method section, the integrity of the collected epochs is questionable. That no control baseline was recorded is also unhelpful. The second doubt relates to the design of the experiment. The repeated measures design, as noted in **section 4.5.**, is likely to inflate values of *p* if adequate corrections are not employed. The study did not employ a MANOVA approach and did not appear to correct values for *p*. The conclusion must be reached, therefore, that the authors' interpretation of the results is suspect.

#### ***4.14. EEG, odour & affect.***

From the evidence reviewed in **Chapter 2 (section 2.4.)**, it is clear that certain odours with differing affective valence have different effects on cognitive performance and self-reported mood. EEG investigations have shown similar disparities with positive and negatively perceived stimuli exerting different effects on the pattern of EEG alpha, often reflected in frontal/anterior asymmetries. A salient defining characteristic of odour, as noted in **Chapter 2**, is its hedonic property. Food odour, in particular, is a robust precipitator of affective response, conditional on the internal state of the subject. It may, therefore, be logical to hypothesize that odours of opposing valence might exert similar effects on the EEG as do previously reported pictorial stimuli (e.g., Davidson, 1992). From what is known of sensory-specific satiety, it

may also be argued that the nutritional state of the subject might also affect the hedonic response to odour, a suggestion which may conceivably be measured, psychophysically, using the EEG.

Study of the lateralisation of emotional processes using EEG has not, until recently, been of great interest to psychophysiology. Early studies of emotion and the brain in humans focused on affective disturbances following head injury. A common finding amongst these and later studies was that left-sided lesions tended to be associated with depressive, negative symptomatology (such as crying, low self-esteem, misery) whereas lesions to the right hemisphere were associated with increased elevation and euphoria (Alford, 1933; Goldstein, 1939; Robinson & Benson, 1981; Sackheim, Greenberg, Weiman, Gur, Gungerbuhler & Geschwind, 1982). These studies demonstrated clearly that the common right-for-emotion hypothesis (Bear, 1983; Bryden & Ley, 1983) was a partial truism at best, a bland caricature at worst and failed to distinguish between the perception of affect and experience of it (Davidson & Tomarken, 1989).

As Davidson (1984) noted, interest in the psychophysiology of affective processes and their lateralisation has lagged behind that for cognitive processes. **Table 4.2.** summarises the principal studies of human adult EEG and affect.

**Table 4.2. summarising principal findings from the main studies of adult EEG response to non-olfactory affective stimuli.**

STUDY	SUBJECTS	ELECTRODES/ BANDS	CONDITIONS	MAIN FINDINGS
Harman & Ray (1977)	20 m; 20 f r-hs	T3/4. All freqs. between 3-30 Hz.	Self-generated emot. memories.	Increase in LH power during +ive affect; decrease during -ive. No effect for RH.
Davidson et al (1979)	17 r-hs	F3/4, P3/4. Alpha.	Response to +ive and -ive TV show segments.	Greater relative LF activ. to +ive film; greater RF activ. for -ive film clips.
Tucker et al (1981)	8 m; 19f	F3/4, C3/4, P3/4, O1/2. Alpha.	Induction of depressive and euphoric states.	Symmetry during euph.; increase in RF activ. during depression; decrease in LF activ.
Schaffer et al (1983)	6 depres. 6 non-dep.	F3/4, P3/4. Alpha.	Eyes closed baseline.	Less LF activ. in dep. than non-dep. No parietal differences.
Tucker & Dawson (1984)	4m; 5f method actors	F3/4, P3/4, C3/4, O1/2. Delta, theta, alpha beta.	Self-generated/ experimentally induced depn. and sexual arousal	Delta-more LF in both conds. esp. during sex. Theta-greater power in FRH leads. Alpha-greater power in dep. cond. esp. in posterior regions.
Ahern & Schwartz (1985)	33 r-h f.	F3/4, P3/4. Delta, theta, alpha beta & total power.	Answering qns. eliciting sadness, excitement, happiness & fear.	Happiness-greater LH activ. than fear. Greater relative LH power in delta and total power to +ive qns. Theta & beta-increase in RH abundance for excit. and fear relative to hap., sad., or neutral.

Ray & Cole (1985)	40 r-h m.	F3/4, P3/4, T3/4. Alpha, beta.	Remembering sad and happy events and imagining pleasant & unpleasant future events.	More beta during positive than negative tasks at temp. and parietal areas; more beta activity at R temporal area during positive than negative tasks.
Davidson et al (1990)	11 r-h f.	F3/4, P3/4, T3/4, C3/4. Alpha & beta 1.	Facial reaction to +ive and -ive film clips; eyes-open baseline.	Facial disgust assoc. with less alpha in RFI comp. with happy cond & baseline but not LH power. Happy cond. assoc. with more L-sided, anterior activ.
Ekman et al (1990)	31 r-h f.	F3/4, P3/4, T3/4, C3/4. Alpha and beta 1.	Smiling reaction while observing +ive films.	Decrease in RF & R ant. temp. alpha power to non-Duchenne smiles comp. with baseline. Similar decrease for pariet. Beta -less activity in RP comp. with baseline.
Tomarken et al (1990)	32 r-h f.	F3/4, P3/4, T3/4, C3/4. Alpha.	Exposure to +ive & -ive film clips. Eyes open & closed baseline.	Increased RF activ. assoc. with heightened affect to -ive films. Increased relative LH activ. assoc. with increased disparity between -ive and +ive responses. F3/4 baseline asymmetry significantly predicted global negative affect.
Jones & Fox (1992)	12 r-h f. rated high in +ive affectivity; 11 r-h f. rated high in negative affectivity.	F3/4, P3/4, T3/4. Alpha.	Exposure to video clips eliciting hap., disgust, sadness and anger. Eyes open & closed baseline.	Greater relative LH activ. to happy clips than sad. or disgust. Greater RH activ. to sad. and disgust than to happy. +ive group showed greater relative LH activ.; -ive group: greater relative

Wheeler et al (1993)	81 r-h f.	F3/4, P3/4, T3/4, C3/4, F7/8, CZ, PZ, FZ. Alpha.	2 sessions, 3 weeks apart, of exposure to video clips designed to elicit hap., fear & disgust. Eyes open & closed baseline.	RH activ. +ive gp. showed greater LH activ. to happy stimuli in temporal region; -ive gp. relative RH activ. +ive gp. showed greater RF activ. to disgust; -ive gp. didn't. +ive gp. showed greater L. activ. at parietal areas; -ive gp.:R activ. High degree of disgust assoc.d with less power in RF comp. with LF. Intense sadness assoc.d with less RF compared with sad. of less intensity.
Schellberg et al (1993)	33 r-h m.	F3/4, P3/4, O1/2, T3/4, C3/4, T5/6, CZ, FZ, PZ. Delta, theta, alpha 1 (7.5-9.5 Hz), alpha 2 (9.5-12.5 Hz), beta 1 & beta 2.	Films processed cognitively or affectively (+ive, -ive & neut. clips). Eyes open & closed baseline.	Greater relative LF activ. assoc.d with reports of more +ive affect to +ive clips and less -ive affect to -ive clips comp. with R activation. Increased LF activ. & decreased RF activ. predicted greater +ive affect to +ive films. Only increased RF activ. predicted increased -ive affect.  Lower delta for the emot. clips at midline comp. with neut. & cog. conds. Greater alpha 1 power for neg. cond. than for cog. but not for others. This power was greater at parietal than occip. areas. Greater beta 2 power for +ive than other films (esp. neg.) at temporal sites.

Biondi et al (1993)	8m; 6f.	SEPs	ERP correlation with MMPI Depression Scale scores.	Subjects scoring above the median showed right frontal lateralisation and shorter P300 right-hem. latencies.
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**KEY:** f= female; m=male; r-hs=right-handers; LH=left hemisphere; RH=right hemisphere; RF activ.=right frontal activation; euph.=euphoria; LF=left frontal; dep.=depressive; RFH= right frontal hemisphere; temp.=temporal; L-sided= left-sided; ant. temp.= anterior temporal; SEPs=somatosensory evoked potentials.

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It is clear from the table that studies by Davidson and others using EEG measures have found hemispheric asymmetries similar in normal subjects which appear to reflect the clinical findings found with brain-damaged patients. The affective stimuli employed normally comprise self-contained film clips, pre-rated for positive and negative affect, although more naturalistic materials have been used by others (e.g., Schelleberg, Besthorn, Pflieger & Gasser, 1993).

An early study by Harman & Ray (1977) suggested that the affective response could be characterised by asymmetrical patterns of EEG activity. Specifically, increases in left hemisphere power were obtained during generation of positive memories with decreases accompanying the generation of negative memories. Greater relative left frontal hemisphere activation to positive film clips and greater right frontal hemisphere activation to negatively rated film clips was later reported (Davidson *et al.*, 1979).

It is important to note the use of the terms activation and power. Power refers to the total activity generated in a given frequency; activation, however, refers to the underlying activity which is usually inversely related to the amount of power. If, for example, increases in alpha power were demonstrated, this would indicate decreased underlying activation; if alpha power decreased, this would indicate increased underlying activation. As Davidson (1988) notes, " Activation is typically defined

operationally on the basis of the methods used in a particular study. In general, all measures assume that increases in activation are associated with increases in neural activity- an increase in the number of depolarizing cells per unit time in large populations of neurons. In the case of EEG, it has been shown that desynchronized activity...is associated with an increase in the number of action potentials from neighbouring populations of neurons."

Other studies by Davidson and his colleagues have demonstrated similar asymmetries to positive and negative emotional stimuli (see **Table 4.2**) although the frequencies they study have been limited, in most investigations, to the alpha band. This frequency is the one argued to be most susceptible to the experience of emotion but a small number of other studies have found affect-related changes in delta (Tucker & Dawson, 1984; Ahern & Schwartz, 1985; Schelleberg *et al*, 1993), theta (Tucker & Dawson, 1984; Ahern & Schwartz, 1985) and beta (Ahern & Schwartz, 1985; Ray & Cole, 1985; Eckman, Davidson & Friesen, 1990; Schelleberg *et al*, 1993). For the slower frequencies (delta), left frontal power has been found to increase to positive emotional stimuli (Ahern & Schwartz, 1985), depression and sexual arousal (Tucker & Dawson, 1984) or has been found to be low in positive conditions relative to other emotions (Schelleberg *et al*, 1993). Theta changes have been less well-documented. Tucker & Dawson (1984), for example, report increased theta in frontal leads relative to other electrode positions but that this increase was not related to affective response. Ahern & Schwartz (1985) note that increases in right hemisphere beta and theta were evident for conditions of excitement and fear relative to happiness, sadness or a neutral condition whereas Ray & Cole (1985) noted no effect of affect on alpha but reported increases in beta at temporal and parietal sites for positive emotion. These authors also observed more beta activity in the right temporal area during positive than negative tasks. Cohen, Rosen & Goldstein (1976) has also reported increased theta activity in the right

hemisphere during sexual orgasm, although the quality of the recording in such a condition would make one doubtful of its integrity.

#### *4.15 Approach-withdrawal behaviour.*

The increases in left frontal/anterior activation to positive stimuli and increased right frontal/anterior activation to negative stimuli reported in the alpha band have been suggested as representing approach-withdrawal behaviour (Davidson, 1984; 1992; Flor-Henry, 1983). This hypothesis argues that affective differences between the two sides of the brain reflect different motivational tendencies (Ehrlichman, 1986). The evidence for the hypothesis has been obtained from normal subjects and from individuals scoring high on depression inventories. Schaffer, Davidson & Saron (1983), for example, found that depressed subjects showed less left frontal baseline activation than non-depressed subjects. Right frontal hemisphere EEG variability has also been reported in depressive patients (Perris, Monakhov, von Knorring, Botskarev & Nikiforov, 1978). However, studies employing different experimental conditions (such as induction of euphoric/depressive states or self-generated depression/sexual arousal) have reported alpha symmetry or no left sided-activation (Tucker, Stenslie, Roth & Shearer, 1981; Tucker & Dawson, 1984). It could be argued that these latter studies contain an element of motor and perceptual activity that is not present when viewing a film and rating it for its affective valence. The studies using film clips may, therefore, be more reliable in terms of the methods they employ. It should be noted, however, that Harman & Ray (1977) who also requested subjects to generate emotional memories reported increased left hemisphere power during positive affect when compared with negative affect. A recent study using evoked potential measures has demonstrated significantly greater right frontal hemisphere lateralisation in individuals scoring high on depression (Biondi, Parise, Venturi, Riccio, Brunetti & Pancheri,

1993). The latency of the P300 in these individuals was also shorter at right hemisphere sites.

The presence of increased left frontal activation has been suggested as a metric of baseline emotional response. Wheeler, Davidson & Tomarken (1993), for example, report that increased left frontal activation and decreased right frontal activation predicted greater affective response to positive films whereas Tomarken, Davidson & Henriques (1990) report that baseline asymmetry at frontal electrodes significantly predicted global negative affect. Taken together with the reports of decreased left frontal activation in depressed subjects, these findings suggest a diathesis model of affective response. As Davidson (1988) notes, "right frontal activation may be necessary but not sufficient for the experience of negative emotion. Its presence may mark a vulnerability for negative affect, given an appropriate elicitor."

#### *4.16. Approach-withdrawal behaviour and odour.*

The relationship between approach-withdrawal and EEG is particularly interesting when considering olfactory perception. As noted earlier, one of the more primitive uses of smell is as a caveat warning an organism of fire, bad food, noxious gases in a similar way to the quality of bitterness which may be used as a warning agent for gustation (see **Chapters 2 & 3**). Hines (1977-8) remarks that the role of the right hemisphere in olfactory perception and spatial relations suggests the use of the sense of smell as a spatial sense, detecting food with the nose, detecting off-odours from rotting food and so on. Rotting food is an excellent example of a stimulus inducing withdrawal behaviour. Fallon & Rozin (1983), for example, suggest that distaste, danger and disgust are the three primary bases upon which the rejection of food is made by humans. The distaste category comprises "sensory-affective" rejection based on

unpleasant taste or "other sensory (typically chemical sense) characteristics". The perception of off-odour or malodour may, therefore, induce aspects of rejection.

In view of the relationship between heightened negative affect and increased right frontal EEG activity, such an odour might be expected to produce similar asymmetries to those generated by pictorial stimuli. However, this hypothesis assumes that the stimuli are equipotential, i.e. they stimulate the same affective response in similar ways. Similarly, it could be argued that pleasant-smelling stimuli would result in increased left frontal or anterior activation (approach behaviour) if visual and olfactory affective responses are comparable. Furthermore, it could be hypothesised that the internal state of the subject might also affect the response to odour, especially food odour. Hungry subjects might react differently to food odour than would a satiated subject (as noted in **Chapter 3**). There are therefore two general hypotheses which may relate to food odour: the first is that unpleasant, particularly alerting, food odours will generate different asymmetries to pleasant food odours; the second is that the hunger state of the subject will modify the subject's psychometric and electrophysiological reaction to the smell of food.

The evidence for odours of opposing valence generating different EEG asymmetries or even differences in the pattern of EEG, is rare. This outcome is not the result of a failure to find or replicate but due to the fact that investigations have not considered possible affective asymmetries in their analyses or considered how the hedonic properties of an odour may be related to their effects on the brain. One study has specifically set out to explore the EEG correlates of olfactory annoyance using discriminant analysis to determine how much of the power spectra was related to subjective ratings (Brandl, Kobal & Plattig, 1980). 80% of the power spectra classified as "very unpleasant" in this study coincided with the subjective ratings of

"very unpleasant". Another study, reported in a conference abstract, compared EEG response from frontal, parietal and occipital sites to the odours of jasmine, lemon and valerian (Kanamura, Okazaki, Sakurai, Okabe, Fukuda & Torii, 1990). These authors reported that a pleasant odour did not always induce a good mood but that self-reports of a "good mood" were related to greater alpha variation in the frontal region. "Bad mood" was associated with variations in the right frontal region. It is difficult to establish, however, how these odours were presented, how the data were analysed, how the "good/bad mood" variations in frontal EEG were related to the odour, or what asymmetry metrics were used. Another conference report has demonstrated a method of Olfactory Evoked Potentials in which subjects generate larger EPs to the pleasant odour at left hemisphere sites and larger EPs to the unpleasant odour at right frontal sites (Miltner & Braun, 1993). Further, indirect evidence, based on the ipsilateral connections between the perceiving nostril and the receiving hemisphere, suggests that negative odours are less pleasant when presented to the right nostril (Ehrlichman, 1986). This finding, however, was obtained when the results of three studies were pooled together. Singly, no one experiment showed a significant difference in affective rating between nostrils.

The evidence to suggest that there exists some association between the hedonic properties of odour and hemispheric lateralisation, therefore, is sparse but suggestive. No study to date has examined the relationship between odour valence and EEG asymmetry. This relationship will be considered in **Chapters 6 & 7**.

#### **4.17. Conclusion.**

Although there appears to be little experimental cohesion in the olfactory EEG literature, current evidence suggests that exposure to odour exerts a fairly direct effect on central nervous system activity. Particular wavebands, especially theta, appear to be

selectively affected according to odour type and odour concentration. Furthermore, interactions between exposure to food odour and ingestion of food have been found to produce marked effects on event-related potentials in some studies. Here, odour is associated with reduced ERPs in hungry subjects but comparatively larger ERPs in satiated subjects.

In the following chapters, a series of three experiments will attempt to answer particular questions relating to the electrophysiological concomitants of olfactory perception and food ingestion. The primary aim of these experiments is to determine the extent of the effect of exposure to odour on the EEG and ERP using food-related stimuli. These odours are varied and hedonically different (the importance of this hedonic difference is explained below). Some investigations have reported no changes in particular wavebands as a result of olfactory stimulation; others have reported either increases or decreases in particular frequencies. A small number of other studies have found variable effects of odour on the ERP. Part of the confusion in the EEG literature may lie in the type and number of odours used, differences in presentation and the period of EEG recording actually selected for analysis between different studies. No study in the ERP literature, for example, has examined the effects of suprathreshold odour on the ERP. To overcome possible internal consistencies of this kind, the present experiments will employ a fairly standard and consistent technique of EEG and ERP recording and data extraction analysis. Details regarding the type of odour selected for ERP recording and ERP measurement are given in **Chapter 5**. Details regarding the type of stimuli used in the EEG experiments are given in **Chapters 6 & 7**.

The second aim of the thesis is to investigate possible pre- and post-prandial differences in the course of the EEG and the appearance of the ERP. A number of studies suggest that changes in the EEG and ERP may reflect diurnal changes in CNS and ANS activity

(**section 4.8.**). Others have considered the role of recency of food ingestion in affecting electrophysiological and metabolic behaviour (**sections 4.8. & 4.9.**). No study has directly examined the effects of meal ingestion on the course of the EEG. If increases in the amount of alpha frequency is reflective of relaxation, for example, one might expect increases in alpha activity post-prandially. Furthermore, if the conclusions of food analogue studies are correct then ingestion of a meal will result in increased ERP amplitude and that this amplitude will be affected by the food's interaction with the perception of food odour. Evidence from the alliesthesia literature suggests that the hedonic rating of food-related items is significantly lower after the ingestion of a meal than before. This outcome is dependent on the time of testing, the content of the meal, the nature of the food stimulus and the sensory properties of the meal. Normally, individuals are asked to rate the taste of particular foods after having ingested various quantities or after experiencing satiety. The effects of ingestion on the appreciation of odour are not clear. Few studies have explored the notion of negative olfactory alliesthesia and this concept will be examined in more detail in **Chapters 5, 6 & 7.** The relationship between the perception of food odour and food ingestion may be reflected in the ERP. Would fed subjects, for example, give larger amplitude ERPs during exposure to food odour than would unfed subjects? If so, would this group-difference in ERP be dependent on attention, satiety or other factors? A further discussion of these questions is provided in **Chapter 5.**

A great deal of the evidence reviewed in **sections 4.14, 4.15 and 4.16.** suggests that stimuli of opposing emotional valence may exert different effects on the EEG. Specifically, the experience of positive and negative stimuli generates significant frontal and anterior EEG asymmetries. Given the hedonic properties of some odours, it may be possible to demonstrate similar asymmetries using olfactory stimuli, if the visual and olfactory stimuli are, in fact, considered equipotential. Furthermore, if an olfactory

stimulus known to be a well-known caveat (such as rotten food) is presented then it is arguable that withdrawal-related frontal asymmetries may occur during the presentation of this type of odour. In the context of the ingestion of food, however, and the general decrease in the hedonic rating of food which appears to occur post-prandially, these asymmetries might be in evidence after ingestion. Would fed and unfed subject's electrophysiological response to a food odour differ? The third, and final, aim of the study is thus to explore the relationship between an odour's hedonic component and the EEG response. This aim is more explicitly discussed in **Chapters 6 & 7**.

In his original study, Moncrieff (1962) cautioned that the EEG may be nothing more than the waste-end product of the brain's activity, "the smoke from smouldering biochemical fires". The aim of the following studies is to observe the smoke and to determine the factors necessary to spark some of these biochemical fires.

## ~CHAPTER 5~

### EXPERIMENT 1: MEAL INGESTION AND EXPOSURE TO FOOD ODOUR: THEIR EFFECTS ON THE AUDITORY ODDBALL ERP TASK. METHOD & RESULTS.

#### EXPERIMENT 1

#### METHOD

##### *5.1. Introduction.*

Studies of the variables affecting the amplitude and latency of the Event-Related Potential have largely concentrated on factors such as stimulus probability, novelty, and divided attention. A few studies, however, have focused on more ecological factors such as mood state, recency of food intake, dual tasks and time-of-day (Heninger, McDonald, Goff & Sollberger, 1969; Kerkhof, 1980; Israel *et al*, 1980; Broughton, Aguirre & Dunham, 1988). A decrease in the amplitude of the N1-P2 complex, for example, has been found to occur from morning to evening (Browman, 1979; Kerkhof, 1982) with the amplitude and latency of the N100 reaching a peak at mid-afternoon and declining thereafter. Others, however, have reported no diurnal differences in the ERP (Heninger *et al*, 1969; Dalbokova & Kolev, 1989; Geisler &

Polich, 1992a,b.), have found larger amplitudes in the evening than morning (Wesenstein *et al.*, 1990) or have reported interactions between "diurnal type" and time-of-day. Kerkhof (1980), for example, found that morning-type subjects gave maximum N105-P194 values at 10 a.m. whereas intermediate evening/morning-preferring types gave largest amplitudes at mid-late afternoon. A similar study has found greater amplitude ERPs in both the visual and auditory modalities in the morning for morning types and the reverse pattern for the evening-types (Kerkhof *et al.*, 1980).

The N1-P2 complex is not the only ERP component to show inconsistencies. The effects of time-of-day on the P300 have generated similar discrepancies. One explanation for this inconsistency has been related to the subject's recency of food ingestion and its effects on P300 amplitude (Geisler & Polich, 1990; Geisler & Polich, 1992a, b). Individuals starved for 6 hours have been shown to give larger amplitude P300 than individuals starved for 3 hours (Geisler & Polich, 1992a). P300 elicited 5 minutes after food ingestion has also been found to be larger than that elicited pre-prandially (Geisler & Polich, 1992a). Unfed controls, however, were not used in these studies in order to avoid the use of a within-groups design. The authors argue that a between-subjects design was more suitable in manipulating the "primary variable of activity-preference, food and time-of-day" and suggest, in support of this design, that it has the added advantage of not disrupting the subject's normal schedule of eating. It would be advisable, however, to include some form of control in order to account for pre-prandial group differences that were present and were not due to the intake of the food. Furthermore, relying on the subject's self-report for when he or she last ingested a meal might not provide the experimenter with much control over the actual food intake pattern of these subjects. In fact, a remedial procedure whereby the subject is fed by the experimenter has also been reported (Geisler & Polich, 1992a). In this study, subjects were fed with peanut butter jelly sandwiches, and apple and a fruit drink with

the micronutrient content of the food unreported. Whether subjects were satiated by this food and whether it was familiar to them as a meal or was novel, was also unreported. Studies from food analogue studies would suggest that the satiety produced by the ingestion of the meal is capable of producing marked alterations in the ERP, as noted in **Chapter 4 (section 4.9.)**. Monitoring the subject's meal intake and recording the degree of satiety would thus appear to be an important variable in the study of meal-related alterations in the ERP.

Food analogue studies using cholecystokinin and saline have argued that the higher amplitude N1-P2 and P300 witnessed in satiated subjects is the result of increased attention to the task (Stacher *et al*, 1979). If this is so, then it is arguable that a food-related stimulus might produce increased distraction in those subjects who remain hungry and would therefore elicit smaller ERP amplitudes, and possibly slower latencies (Stacher *et al*, 1979; Pietrowsky *et al*, 1989). Food odour may be capable of distracting a hungry subject but not a satiated one; reduced amplitudes during exposure to food odour should then be apparent in hungry subjects but not in satiated subjects. There is some evidence to suggest that exposure to odour does influence the amplitude of the ERP (Lorig, Huffman, DeMartino & DeMarco, 1991), but the use of food odour and the combination of ingestion with exposure to food odour has not been considered. This latter study, in fact, found increases in amplitude as a function of exposure to odour and increasing concentration which seems to be at odds with the explanation given in the study that the odour was distracting (see **Chapter 4, section 4.11.**).

In the following experiment, the involvement of time-of-day, food ingestion and olfactory exposure to the alteration of N100, P200 and P300 amplitude and latency are assessed in an auditory oddball task using a within-subjects design. In order to ensure that the food eaten is typical of the subject's normal diet, hot, cooked versions of

familiar food are used as the experimental group's lunch. To ensure that ingestion effects may not be the result of differences between groups, both the experimental group and control group are tested twice, once before mid-day, and once an hour later. The experimental group receives its meal during the inter-session interval. If diurnal variation is instrumental in producing alterations in ERP amplitude, then no EP differences between groups should emerge at either testing session. If lunch ingestion does affect the P300 in a manner similar to that reported elsewhere, then amplitude should markedly increase. Furthermore, if the subject's satiated state has any attention-related effect on the size of the ERP, then the combination of exposure to food odour and hunger in fasted subjects should result in lower amplitude ERPs compared with subjects who are fed.

### 5.2. *Subjects.*

16 right-handed non-smokers responded to an advertisement posted in the department of psychology and around campus at the University of Warwick, requesting volunteers for an experiment in psychophysiology. Age ranged from 18 to 44. The subjects were randomly assigned to two groups of eight: Group 1 (2 males; 6 females) would receive no lunch in between the two testing sessions; group 2 (4 males; 4 females) would receive a prescribed lunch. Handedness was measured using a variation of Annett's Hand Preference Questionnaire (Annett, 1970; see **Appendix B1**). Although one group was balanced for sex, sex was not considered a variable in either this or the experiments reported in **Chapters 6 and 7**. The relevance of the sex of subjects in olfactory testing continues to be controversial (Koelega, 1994). While some studies report female superiority for olfactory detection and identification and superior olfactory sensitivity in women (e.g., Wysocki & Gilbert, 1989; Doty, 1991) others have shown better detection for *some* odours but not others (Cain & Gent, 1991; Koelega & Koster, 1974; Koelega, 1970; 1994). Since the present experiments do not examine explicitly

the phenomenon of olfactory sensitivity nor the superior ability to identify, the variable of sex was not controlled in a systematic way. It was considered sufficient that subjects be able to smell the odours presented and since all odours were delivered at suprathreshold concentrations, this criterion was met. It is possible, however, that female subjects might differ from their male counterparts in terms of the amount of food consumed or in the ratings given to food odours after ingestion. However, although some previous studies of alliesthesia and sensory specific satiety have reported greater food intake in males than females (e.g., Rolls *et al*, 1982; Rolls *et al*, 1984) no sex differences have been reported in the subjective ratings of the pleasantness of the stimuli used (Duclaux *et al*, 1973; Rolls *et al*, 1982; Rolls *et al*, 1984). Since the purpose of the meal was to induce satiety, it was assumed that all subjects would eat as much as they could to fullness. Thus, although males may eat more of the food than females, both sexes would be similar in terms of the satiety experienced. Any subject - regardless of sex- who followed a strict dietary regime was considered unsuitable for the experiment and rejected at the recruitment stage.

Subjects were requested to have eaten no food for at least three hours before the start of the experiment. Further instructions included the avoidance of the use of perfumed products on the day of the experiment, the avoidance of the ingestion of any spicy, pungent meals on the evening before and morning of the experiment and any heavily caffeinated products (coffee, tea, cola) on the day of the experiment. In order to determine the subjects' discriminatory ability and to screen for anosmia, a forced-choice odour discrimination test was administered prior to the testing session. This required the discrimination of a blank from three detectable odours and the identification of the three odours (see **Appendix B5**). All subjects successfully completed this test and all reported no neurological injury, physical ailment, allergy or the use of medication.

### 5.3. Procedure.

Subjects were tested individually and entered the laboratory at either 11 a.m. or 12 p.m. having followed a fasting regime for three hours before arrival. After screening for anosmia, they were informed that they were to participate in an experiment in cognitive neuropsychology. 28 tin-electrodes attached to an elasticated cap were applied to the scalp following the 10/20 electrode placement system and referenced to linked earlobes. This cap was attached by elastic straps to a band placed around the subject's chest. This ensured that the cap remained in a fixed position throughout the experiment. Electrodes were filled with high-conducting electrode gel (potassium/sodium chloride Electro-gel). Impedance was below 10kohms. After the application of the electrodes, subjects were tested in an olfactorium- a well-ventilated, aluminium-shielded, purpose-built room designed for olfactory experimentation. This room covers an area of 7 m<sup>3</sup> and contains vents for the dispersal of lingering odour. Temperature inside the room was kept constant at 19°C. Subjects were fitted with occluded goggles to prevent extraneous visual stimulation and were instructed to keep their eyes closed in order to reduce ocular artifact. The nature of the auditory oddball task was explained to them and headphones applied. Subjects were seated in a comfortable arm-chair and were requested to keep as still as possible, with their feet on the ground and their hands in their laps or on the arms of the chair. This instruction was given in order to obviate beta artifact produced by gross muscle movement. Before the task began, subjects were further requested to breathe in through the nose and exhale via the mouth (in order to prevent retro-nasal breathing) and were told to feel as relaxed as possible. When subjects reported being adequately comfortable, the nature of the task was re-iterated and the ERP recording began (see section 5.4, below). The presentation of the odours is described below.

After completing the oddball task, subjects were led out of the olfactorium and were assigned to one of two conditions. Half of the subjects remained in the laboratory under experimental supervision; the other half were led away to receive a prescribed lunch. This standard hot lunch comprised a first course of vegetable soup (Heinz, 210 g) with brown roll followed by a main course of baked beans (Tesco, 220g) with baked potato (400g, unbuttered), and a cup of concentrated orange juice (140 ml). The foods were selected were relatively high in carbohydrate, although no attempt was made to control specifically the nutritional aspect of the meal. The choice of food was made on the evidence reviewed in **Chapter 3** with the aim of presenting subjects with foods which they would find satiating and which would reduce subjects' feelings of hunger. The results obtained supported this choice with all subjects who received the prescribed food reporting satiety after consumption. The cooked foods were heated in a 650 watt microwave oven in accordance with manufacturer's instructions.

Following this thirty minute break, subjects were led back into the laboratory and electrodes were re-applied. Subjects performed the same task as in the first session with odours presented in counter-balanced order. After the completion of all five trials, the electrodes were removed and subjects completed a brief psychometric test which required them to rate each odour that had been presented in the experiment, on three dimensions: pleasantness, strength and familiarity. These dimensions were represented as 8.5 cm. analog Likert-like line scales with poles representing pleasant-unpleasant (0-8.5 cm.), strong-weak (0-8.5 cm.) and familiar-unfamiliar (0-8.5 cm.) [see **appendix B2**]. These poles were alternately reversed to detect response set. Subjects marked their responses along these dimensions and were allowed to sniff each of the odours for as long as they wished. They were told, however, to complete the task as briskly as possible and not to dwell on any particular odour. Subjects were also asked to identify

each of the odours. After completion of this test, subjects were debriefed, paid and received a free brain-map.

#### *5.4. Task.*

The subjects' task was to perform a standard auditory oddball counting exercise. This requires the silent counting of the number of low tones in a series of high and low tones where low tones comprise approximately 25 % (32 tones) of the total stimuli. Although some studies have favoured finger tapping as an observable, behavioural indicator that the tones are being recognised, silent counting was employed here in order to minimise movement. Silent counting has also been found to produce clearer ERPs than do finger-tapping paradigms (Polich, 1987). The tones were delivered via headphones. This task was undertaken six times. The first trial was a no-odour practice designed to familiarise the subject with the task. The second trial comprised the control condition where no odour was presented. Trials 3-6 were undertaken in the presence of one of four food odours, in counter-balanced order. The odours were: coffee dissolved in hot water (Nescafe, 112 ml, presented in a plastic beaker), vegetable (2 microlitres of concentrate presented on a perfumer's strip; this odour emitted an odour similar to that of potato), lemon (2 microlitres) and strawberry (2 microlitres). Pilot testing demonstrated the suprathreshold quality of the odour but odours were also isointense. Apart from the coffee, all odorants were supplied by Quest International.

The odours were selected on the basis of their representativeness of the sweet-savoury dimension and on their relative familiarity. The "vegetable" odour used in the experiment mirrored that of the baked potato used in the lunch. The odour of coffee was selected to represent the aroma of a well-known beverage which subjects would associate with a lunchtime meal. This odour is relatively well-identified (Desor &

Beauchamp, 1974). Both the lemon and strawberry odours were chosen on the basis of their nearness to the category of dessert. These are normally regarded as pleasant-smelling.

The odours were presented approximately 7 cms from the midline of the subject's face at the beginning of each trial and removed at the end of the final tone. A 1-min interval was allowed between each trial in order to allow the lingering smell of the previous odorant to disperse. This "rest" period also allowed subjects to move their limbs and maintain alertness before the beginning of the next trial.

#### *5.5. ERP recording apparatus.*

Auditory evoked potentials were recorded using a Neuroscience Brain Imager Series III model (see **appendix C1**). Tones were generated at 70-80 dB and were of 1 second duration. Standard (high) tones were set at 1KHz; target (low) tones were set at 500Hz. One trial comprised 32 target tones, i.e. 25% of the total number of tones. Filters were set at 1.05 and 80Hz. Waveforms were averaged on-line.

#### *5.6. Data reduction.*

A sub-set of electrodes was selected for analysis. These electrodes were the customary EP electrodes (FZ, CZ, PZ) and eight others selected to represent frontal (F3, F4), central (C3, C4), parietal (P3, P4) and auditory-temporal regions (TCP1, TCP2) [see **Fig. 5**]. The additional electrodes were chosen in order to provide a "spread" of electrodes covering the major lobe locations (Johnson, 1993). ERP records were visually inspected for artifact. Any record contaminated by eye-movement artifact was removed. Five EPs were used in subsequent analysis: Target N100, P200 and P300 (target condition) and standard N100 and P200 (standard condition). The largest negative wave occurring between 50 and 140 milliseconds following stimulus onset

LEFT

RIGHT

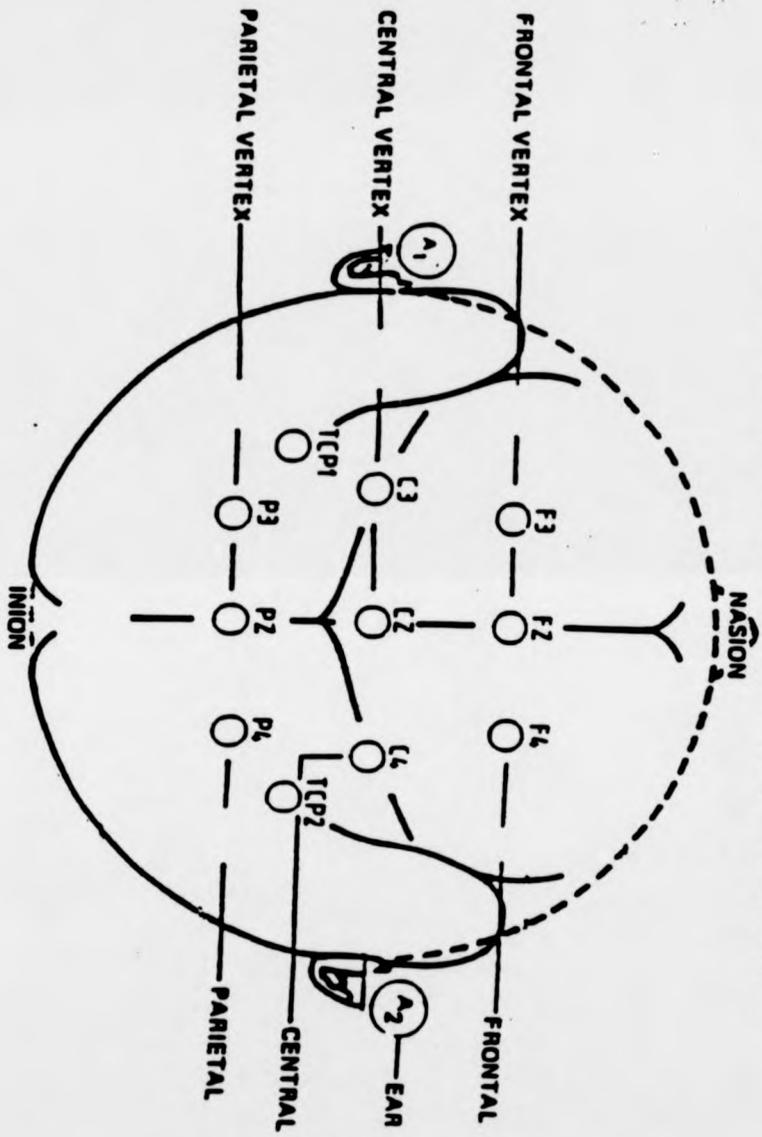


Fig. 5. Electrode array used for analysis in experiment one.

was designated N100; the largest positive waves appearing between 140 and 250 and between 250 and 400 were designated P200 and the P300 respectively. Peak latency was defined as the point of maximum amplitude within the designated time-window.

## RESULTS

### *5.7. Psychometric data.*

#### *5.7.i. Odour identification.*

To determine any differences between odours in terms of their identifiability, Cochran's test for repeated measures design and two response categories was applied to the data. Following the procedure adopted by Davis (1981), odours were assessed as either correct or incorrect and assigned the value of '0' if incorrectly labelled (or if a subject was unable to retrieve a name or descriptor) and '1' if the odour was correctly identified. Also within this category resided any identification which belonged to the same narrow class as the stimulus odour. Although this identification criterion was applied pre-analysis for fear of a small number of direct identification hits, it was rarely used since the majority of subjects labelled the odours correctly. A pair-wise sign test revealed no significant differences between odours for identifiability (coffee vs strawberry,  $p=0.063$ ; coffee vs lemon,  $p=0.125$ ; coffee vs vegetable,  $p=0.25$ ; strawberry vs lemon,  $p=1.00$ ; strawberry vs vegetable,  $p=0.68$ ; lemon vs vegetable,  $p=1.00$ ). **Table 5a** shows the odours ranked for identifiability and familiarity, from most identifiable/familiar to least identifiable/familiar (see **section 5.7.ii.**, below).

**Table 5a.** Odours rated for familiarity (most to least familiar, means with standard deviations in brackets) compared with odours most correctly identified.

Familiarity	Identification
Coffee 0.23 (0.3)	Coffee
Lemon 0.56 (0.9)	Vegetable
Strawberry 1 (1.9)	Lemon
Vegetable 1.2 (1.03)	Strawberry

**5.7.ii. Psychometric ratings: pleasantness, strength and familiarity.**

A two-way repeated measures analysis of variance was applied to the psychometric data with odour as a within subjects factor and lunch as the between subjects factor. Means and standard deviations for the strength and pleasantness dimensions are displayed in **Table 5b.**

**Table 5b.** Odours ranked for pleasantness (most pleasant to least pleasant) and strength (strongest to weakest). Means with standard deviations in brackets.

Pleasantness	Strength
Strawberry 1.18 (1.6)	Coffee 0.63 (0.6)
Lemon 1.26 (1.5)	Strawberry 0.84 (1.01)
Coffee 2.54 (2.8)	Vegetable 1.00 (0.8)
Vegetable 5.88 (2.3)	Lemon 1.27 (0.9)

No significant main effect of lunch was found on any of the dimensions (pleasantness: [F (1,14)=0.122,  $p=0.732$ ]; strength [F (1,14)=0.007,  $p=0.933$ ]; familiarity [F (1,14)=1.71,  $p=0.212$ ]). Neither was a significant main effect obtained for odour strength or familiarity (strength: [F (1,14)=1.84,  $p=0.172$ , Greenhouse-Geisser corrected]; familiarity [F (1,14)=2.21,  $p=0.100$ , G-G corrected]). Correlations between the pleasantness ratings and strength ratings (see **Table 5c** below) indicated no statistically significant relationship between these two dimensions for any odour indicating that the odours were not rated for pleasantness on the basis of strength and vice versa. From **Table 5b**, however, it would appear that there are marked differences in the subjective pleasantness ratings, especially between vegetable and the other odours.

A significant effect of odour did emerge for odour pleasantness (F (1,14)=21.49,  $p<0.001$ , G-G corrected). Post-hoc Tukey's tests revealed that the effect was due to the vegetable odour. This odour was rated significantly less pleasant than coffee ( $p=0.005$ ), strawberry ( $p=0.00023$ ) or lemon ( $p=0.00025$ ). **Fig. 5.i.** illustrates this difference more clearly.

**Table 5c.** Correlations between dimensions by odour. Significant values are signified by an asterisk ( $p < 0.05$ ).

**COFFEE**

	PLEASANTNESS	STRENGTH	FAMILIARITY
PLEASANTNESS	1.00		
STRENGTH	-0.023	1.00	
FAMILIARITY	-0.018	0.631 *	1.00

**STRAWBERRY**

	PLEASANTNESS	STRENGTH	FAMILIARITY
PLEASANTNESS	1.00		
STRENGTH	0.257	1.00	
FAMILIARITY	0.215	-0.073	1.00

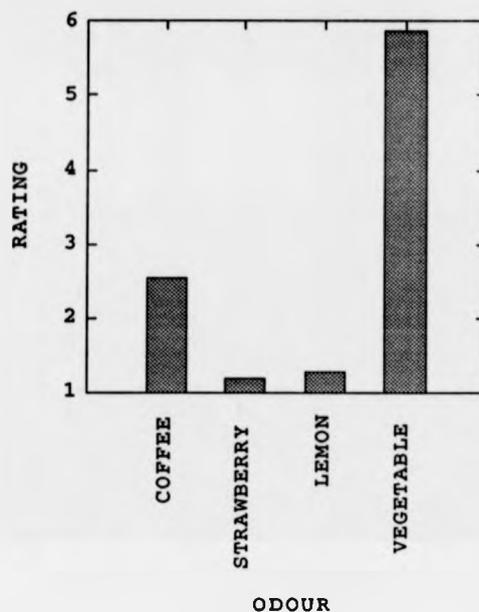
**LEMON**

	PLEASANTNESS	STRENGTH	FAMILIARITY
PLEASANTNESS	1.00		
STRENGTH	0.253	1.00	
FAMILIARITY	0.152	0.454	1.00

**VEGETABLE**

	PLEASANTNESS	STRENGTH	FAMILIARITY
PLEASANTNESS	1.00		
STRENGTH	-0.428	1.00	
FAMILIARITY	-0.13	0.309	1.00

## PLEASANTNESS RATINGS FOR ODOURS



*Fig. 5.i. illustrates differences between odours on the pleasantness dimension (0=pleasant; 8=unpleasant).*

There was no significant main effect of odour for familiarity or strength and no significant odour x group effects were found for any of the dimensions.

### **5.8. ERP results.**

#### **5.8.i. Tone counting.**

The responses to the counting task were submitted to a two-way analysis of variance with odour and group representing the within subjects factor and between subjects

factor, respectively. There was no main effect of odour [ $F(1,14)=0.18, p=0.80$ ] or group [ $F(1,14)=1.45, p=0.25$ ]. No significant odour  $\times$  group interaction was obtained.

#### *5.8.ii. Amplitude data.*

The data for each ERP component were analysed using a three factor (odour  $\times$  group  $\times$  time-of-day) repeated measures analysis of variance (SYSTAT Inc. statistical software). Each component (as well as each ERP measure- amplitude and latency) was analysed separately.

##### *(a) Effects on N100 amplitude.*

There was no significant main effect of odour at any electrode site for the N100 to target (low tones) or standard (high tones) stimuli. No group or time-of-day effects were obtained. Neither were any of the group  $\times$  odour, time-of-day  $\times$  group, nor odour  $\times$  group  $\times$  time-of-day interactions significant.

##### *(b) Effects on P200 amplitude.*

###### *(b) i. Was there an effect of group or odour?*

A significant main effect of odour was obtained at FZ and at auditory/temporal regions for the standard P200. All  $p$  values are corrected using Greenhouse-Geisser. (FZ: [ $F(4, 48)=4.11, p<0.01$ ]; TCP1: [ $F(4,24)=3.39, p=0.04$ ]; TCP2 [ $F(4,20)=4.34, p=0.03$ ]). The main effect at FZ was limited to amplitude for the blank being greater than that for strawberry ( $t=4.01, df(13), p=0.001$ ). Since the number of pairwise comparisons is rather large, the Bonferroni principle was invoked in order to produce a more conservative  $p$  value ( $0.05/\text{number of pairwise comparisons}$ ) and to reduce the likelihood of Type 1 errors. Thus, at the left auditory/temporal area the odour of strawberry was associated with a larger P200 than was the odour of lemon ( $t=3.62, df$

(10),  $p=0.005$ ) or vegetable ( $t=4.16, df(7), p=0.004$ ). Right-sided amplitude, however, was larger during exposure to the odour of coffee than vegetable, although the conservative estimate of  $p$  would not allow this to be declared significant ( $t=2.84, df(6), p=0.03$ ). There was no significant main effect of group on either the target or standard P200 at any electrode site and no main effect of odour was obtained for target P200.

*(b) ii. Was there an effect of time-of-day?*

Differences in amplitude between the two testing sessions were obtained in order to explore possible diurnal changes in the ERP, to the exclusion of lunch and odour. A significant main effect was obtained at the right "central" region for standard P200 [C4:  $F(1,11)=5.43, p=0.04$ ] with amplitude in this area being higher in the afternoon than in the morning ( $t=2.12, df(12), p=0.05$ ). There were no other main effects of time-of-day for standard or target P200.

*(b) iii. Did exposure to odour interact with group or time-of-day?*

An odour x time-of-day interaction was obtained for the left frontal region [F3:  $F(4,44)=4.07, p=0.015$ ]. This interaction was due to a trend for the amplitude of the standard wave during exposure to the vegetable odour to be larger in the afternoon than the morning ( $t=2.08, df=12, p=0.06$ ). There were no other odour x time-of-day interactions for standard P200. No significant group x time-of-day interaction was obtained for standard P200 amplitude.

A significant three-way interaction was obtained for target P200 at CZ [ $F(4,44)=3.11, p=0.049$ ] and FZ [ $F(4,28)=4.412, p=0.02$ ]. Post-hoc tests revealed that the effect at CZ was restricted to the differences between the a.m. and p.m. amplitude of the lunch group. Target P200 amplitude was significantly larger after lunch than before ( $t=2.63,$

df (6),  $p=0.039$ ) and appears to mirror the effects obtained previously in other studies with the P300. The effect at FZ showed that the control group showed a significant decrease in amplitude to the vegetable odour in the afternoon ( $t=2.59$ , df (7),  $p=0.036$ ).

*(c) Effects on P300 amplitude.*

No main effect of odour, group or time-of-day was obtained for P300 amplitude at any electrode site and no significant interactions emerged.

*5.8.iii. Latency data.*

*(a) Effects on N100 latency.*

There were no significant main effects of odour or group for any electrode site for either target or standard N100 latency although FZ showed a significant effect of time-of-day for the target tones only [ $F(1,9)=5.53$ ,  $p=0.043$ ]. N100 latency at this location was significantly longer in the afternoon than the morning ( $t=2.31$ , df (12),  $p=0.040$ ). A significant odour x time-of-day interaction was also obtained for target tones in the left parietal region [P3:  $F(4,12)=8.09$ ,  $p=0.02$ ]. This interaction was due to the vegetable odour which produced longer latencies in the afternoon compared with morning performance ( $t=2.82$ , df(11),  $p=0.017$ ).

*(b) Effects on P200 latency.*

*(b) i. Was there a main effect of group, odour or time-of-day?*

A significant main effect of time-of-day was obtained at FZ for the target tones ( $F(1,11)=4.87$ ,  $p=0.049$ ). Post-hoc analysis revealed that a decrease in latency was evident in the afternoon compared with morning ( $t=2.49$ , df (10),  $p=0.032$ ). There was no main effect of odour or group on P200 latency for either the target or standard stimuli.

*(c) Effects on P300 latency.*

*(c) i. Was there a main effect of odour, group or time-of-day?*

A significant effect of time-of-day was obtained at both left and right frontal sites [F3: (F (1,5)=7.08,  $p=0.044$ ); F4: (F (1,7)=19.00,  $p=0.0032$ )]. At both locations, latency was longer in the afternoon than in the morning [F3: ( $t=2.93$ ,  $df(6)$ ,  $p=0.026$ ); F4: ( $t=4.65$ ,  $df(8)$ ,  $p=0.002$ )]. No significant main effects of odour or group were obtained for P300 latency, neither were any three-way interactions obtained.

*5.9. Discussion.*

*5.9.i. Alliesthesia.*

There were no post-prandial changes in the hedonic ratings of the food odours obtained in the present experiment, a finding which is at odds with some previous findings (e.g., Ducleaux *et al*, 1973). At the extreme end, it is arguable that genuinely olfactory alliesthesia does not exist as a replicable phenomenon even though negative gustatory alliesthesia can be quite clearly demonstrated. In support of the extremist approach, a number of studies which have sought to demonstrate olfactory alliesthesia have either found little effect of ingestion on hedonic perception of odour (Warwick *et al*, 1993) or have engineered satiety by giving infusions of glucose (Cabanac, 1971), thus depriving the subject of the sensory information obtained from normal eating. Yet, the lack of replication does not explain the appearance of such a finding in the first instance. An alternative, less extreme, explanation is that the pleasantness rating of food would be obtained on condition that subjects rated food odours that were part of the meal ingested between rating sessions. In the present experiment, however, such an hypothesis was tested: Fed subjects rated a vegetable smell closely resembling that of baked potato (part of the lunch) but did not give significantly different pleasantness ratings to those given by unfed controls. Furthermore, in the one study which did report negative alliesthesia in a realistic setting, the odours which showed evidence of alliesthesia did not comprise

part of the experimental meal (Ducleaux *et al*, 1973). The post-prandial hedonic ratings of the odours of cheese, fish and beef were lower than pre-prandial ratings even though these foods were not eaten. As a supplementary hypothesis, one could argue that those odours associated with the third-course of a meal (e.g., coffee, dessert) might be expected to increase in pleasantness following the ingestion of a savoury main course, yet this effect was not found in the present study and would appear to confirm Ducleaux *et al* (1973)'s stable pre- and post-prandial ratings for the odour of coffee.

A further possibility is that the range and number of odours used in the present study was too limited to allow post-prandial effects to be found. In one study, for example, nine food odorants were rated pre- and post-prandially while only three odours showed evidence of negative alliesthesia (Ducleaux *et al*, 1973) even though another study has used only one odorant and reported changes in the odour's rating for pleasantness after intake of glucose (Cabanac, 1971). Thus the possibility arises that the hedonic perception of only specific types of food odour are specifically affected by ingestion of food or satiety so that the use of a large number of odorants will determine those odour that *are* affected (this possibility is addressed in the next experiment, **Chapter 6**).

#### **5.9.ii. Did lunch affect the P300 or any other ERP component?**

The results of experiment 1 do not appear to support the finding that recency of food ingestion is associated with increased P300 amplitude. Geisler & Polich (1992a) found that food ingestion three hours prior to the experiment was associated with a significant increase in P300 amplitude when compared with subjects who fasted for six hours. No such increase in P300 was observed in the present experiment, however, although a significant alteration in the amplitude (and latency) of other ERPs was found to be related to lunch ingestion. Target P200 amplitude, for example was significantly higher in the Lunch group than in controls.

In view of the striking lunch-related changes in ERPs reported elsewhere, the lack of a food effect on P300 is surprising. **Table 5d** illustrates the methodological differences between the present study and that of Geisler & Polich (1992a, b). Differences in methodology are often cited in ERP studies as factors responsible for producing negative results or inconsistency of results between studies. In the present experiment, several methodological procedures were adopted in order to improve the validity of study. In other studies, subjects were instructed not to eat for a given period prior to testing, either three hours or six (Geisler & Polich, 1992a). Subjects in another study were instructed not to eat from the evening prior to the day of the experiment, i.e. subjects were fasted for 15 hours (Geisler & Polich, 1992b). In the present study, subjects were requested to refrain from eating for three hours prior to the first testing session. Given that the inter-session interval was of approximately one hour's duration, the control group would have fasted for at least four hours prior to the second, "post-prandial" session. All subjects gave self-reports of feelings of hunger at the end of the first testing session. Those subjects fed prior to the second testing session gave self-reports of satiety and fullness.

Thus, although not controlled in a particularly Draconian way, the nutritional status of the subject was controlled in a fashion not reported in previous investigations where the subjects' ingestion of food was not controlled, where subjects' self-report regarding their affective and nutritional state (full/not full, hungry/not hungry) was not considered and where the amount of food eaten was not monitored. The focus of previous studies appears to have been, perhaps erroneously, on the physiological effects of recency of intake rather than on the 'psychological' effects of intake.

**Table 5d** illustrates methodological differences between the present experiment and those of Geisler & Polich (1992 a, b).

	<u>GEISLER &amp; POLICH</u>	<u>MARTIN (1993)</u>
<b>1992 a i.</b>	(1) 3 or 6 hour fasting period. (2) 24 subjects in each condition. (3) FZ, CZ & PZ electrodes.  (4) Tones every 2 seconds. (5) 4 trial blocks (20 targets).  (6) No subject fed. (7) 1000Hz/2000Hz tones. (8) Finger-tapping discrimination.	3 hour fasting period. 8 subjects in each. FZ, PZ, CZ, TCP1, TCP2, F3, F4, C3, C4, P3, P4. Tones every 1 second. 5 trial blocks, presented twice (32 targets). Subjects fed. 500Hz/1000Hz tones. Silent counting.
<b>1992 a ii.</b>	(1) Subjects fasted for 15 hours. (2) 12 subjects per condition. (3) 3 blocks of trials presented before and 5 and 30 minutes after ingestion. (4) Snack food. (5) Plus (7) & (8) as above.	As above. As above. 5 blocks presented before and 15 minutes after ingestion. Hot, cooked meal.
<b>1992 b.</b>	(1) 8 groups of subjects (N=64). (2) Groups divided by activity preference. (3) Fasted for 3 or 6 hours. (4) A.M. group tested at 8 or 11 a.m. P.M. group tested at 5 or 8 p.m.	As above. Not divided. As above. All subjects tested at 11 a.m. and 1 p.m.

The nature of the ingested food in the the present study also differs from that previously reported. Geisler & Polich (1992a), for example, presented subjects with snack-like material. Other studies, such as those reviewed in sections 4.9. & 4.12 of Chapter 4 and in section 5.1., have used food analogues such as cholecystokinin

(vs a saline infusion), or in alliesthesia studies, glucose (Cabanac, 1971; 1979). The subjects in the current study received a hot, cooked meal, the contents of which were designed to be as close to a hot, satiating lunch as possible. The foods were substantial and contained large amounts of carbohydrate. Thus it is possible that these differences between the meals presented in the different experiments may be responsible for the absence of the P300. This is not to argue that recency of meal ingestion has no significant effect on the P300 but that different meals with markedly different constituents might affect brain electrophysiology differently. Perhaps more importantly, the alteration in P300 might be dependent not only on the type of food eaten but on the affective response of the subject to the ingested meal, i.e. the subject's feelings of hunger and satiety. The authors of other studies have argued, however, that the effects of food ingestion on the P300 demonstrate a role for meal consumption in the alteration of brain metabolism (Geisler & Polich 1992 a, b). Given this hypothesis, it is surprising that a standard, cooked meal should have had no effect on brain metabolism. The times of testing were comparable between studies so that differences in the rate of metabolism could not plausibly be responsible for the discrepancy.

There are also minor differences between these sets of studies although these differences would not appear to have affected the results in any radical way. The number of tone-blocks presented differed but not markedly so; the pitch of the tones also differed with Geisler & Polich (1992a, b) using higher pitches and larger qualitative differences between low and high tones (1000Hz and 2000Hz compared with the present study's 1000Hz and 500Hz). The difference in pitch, however, could not realistically be argued to have affected the outcome of these experiments. Subjects in both were still able to distinguish one quality of tone from another and were thus capable of the discrimination required in order to elicit an auditory oddball ERP. Another source of difference may be the method of discrimination that the two studies

use. Geisler & Polich (1992a), for example, required subjects to indicate the presence of a target tone by tapping their fingers; in the present study, subjects silently counted the numbers. Silent counting has been reported to be a more effective method of eliciting ERPs (Polich, 1987) so if any effects of lunch did exist, silent counting might have enhanced their appearance.

In the present study, there was a significant group x odour x time-of-day interaction for target but not standard P200 amplitude, supporting a previous report of diminished N1-P2 amplitude in subjects satiated by a bolus injection of CCK and exposed to the noise and smell of meal preparation (Stacher *et al.*, 1979). Subjects in the lunch group gave significantly higher P200 amplitude post-prandially than did control subjects who received no meal. It has been argued that the P200 and P300 target components may overlap considerably thus resulting in the effects on one being masked by the other. Given this possibility, it is open to debate whether the effect of lunch found on target P200 amplitude in the present study is simply a concealed effect on overlapping components. It is more probable, however, that the effect of recency of food intake may be general to late positive-going ERP changes and not specific to the P300. Geisler & Polich (1992a) noted increases in P200 amplitude in subjects who had recently eaten a meal compared with those who had not and suggest the possibility that the lunch effect may not be specific to a particular ERP. The results from the present study lend support to this hypothesis.

### *5.9.iii. Did odour affect any ERP component?*

Contrary to the previous finding on odour and ERP, no effect of odour was obtained for the P300. A significant main effect of odour was obtained for standard P200 amplitude, however, at CZ. Here, the EP amplitude during exposure to strawberry was significantly smaller than that to a blank, irrespective of recency of ingestion. At

auditory-temporal sites, there were additional bilateral olfactory influences for standard stimuli with right-sided P200 amplitude being greater to coffee than to vegetable and left-sided P200 amplitude being greater to strawberry than lemon. The vegetable odour was also associated with shorter P200 amplitude in the unfed group during the second recording session. The odour x time-of-day x group interaction obtained demonstrates for the first time that unfed, hungry subjects' P200 amplitude may be selectively diminished by exposure to a food odour.

Selective diminution of the P200 has been reported following distraction (Miltner, Johns, Brach & Larbig, 1989) and lowered attentional demands (Courchesne, Courchesne & Hillyard, 1978). It is plausible that the divided nature of presenting an ERP task with olfactory exposure might generate similarly stunted P200 amplitudes when compared with a blank control. This, in fact, was apparent but for the strawberry odour only. It was also apparent for the three-way interaction obtained. Subjective self-reports suggested that the odour of strawberry was rated the most pleasant of those used but was also the least well-identified. It is possible that the difficulty in identifying such an odour might have produced this attention-related diminution. Furthermore, odour had selective effects at other sites. If the distraction/lack of attention hypothesis of ERP diminution is correct, then the findings here suggest a hierarchy of distractability based on individual electrode sites and odours. Thus vegetable odour produced greater distraction than the odour of coffee and lemon odour produced greater distraction than the odour of strawberry at right and left temporal sites respectively. The use of citrus odours to increase alertness has been reported in a number of Japanese industries (Manley, 1993). It is possible that odour of lemon used in the present study diminished the P200 as a result of its alerting properties. The odour of strawberry, on the other hand, is not as sharp as that of lemon and was rated the most pleasant odour. It is arguable that when the two odours are compared, their

effects, at least in one specific brain region, are different. It is also notable that this effect occurred at the anterior, left hemisphere region which has been reported in various EEG studies to be involved in the experience of positive, emotional stimuli (Davidson *et al*, 1979; Ahern & Schwartz, 1985; Wheeler *et al*, 1993). That the pleasant odours exerted their effects at this particular region and that the most pleasant odour was associated with a significantly greater increase in amplitude when compared with the odour of lemon, suggests that this region may be specifically involved in the processing of this form of affective information. Evidence also suggests right-sided, anterior involvement in the processing of negative emotional stimuli (Davidson *et al*, 1990; Tomarken *et al*, 1990; Jones & Fox, 1992). In the present study, right-sided anterior effects of odour were confined to the least pleasant odour, that of vegetable, and coffee, a pleasant odour. The diminished amplitude found during exposure to vegetable is perhaps not unexpected given its unpleasantness and the distraction it may thus have caused. Evidence from cognition studies has suggested that distraction from a task is often reported as a result of exposure to malodour (Lewis *et al*, 1970; Rotton *et al*, 1978; 1979). Post-experimental debriefing also suggested that subjects found this odour alerting so that the diminished ERP resulting from exposure to vegetable odour may again be related to the alerting (and, ergo, distracting) property of the odour (cf. lemon vs strawberry). That the effects should have been elicited at the right-anterior region also suggests a role for this area in the mediation of negative, affective stimuli. Although the evidence for this asymmetry specifically from ERPs is sparse, the hypothesis is compatible with findings from studies analysing spontaneous EEG.

The olfactory findings reported above are contrary to those reported by Lorig *et al* (1991) who noted increases in P200 and P300 amplitude as a function of increasing concentration of galaxolide. These authors suggested that the results may have been due to decreased attention produced by exposure to the odour (as noted in **Chapter 4**,

section 4.11.). Of what is known regarding P200 and P300 determinants, however, this seems unlikely. Given that the odour was not presented at uniformly suprathreshold concentration in this study, it is possible that the weak nature of the concentrations may have focused attention on the counting task and that subjects found the exposure pleasant and relaxing thus eliciting significantly greater amplitude with increasing concentration. An alternative, complementary explanation might be that the odours used in the present experiment differed in some important way to that of Lorig *et al's* (1991). The odour in the latter study was a commercial odorant often used as the musk base for perfumes. The authors note that this odour would be relatively unfamiliar to subjects or would be difficult to identify. They also suggest that exposure to this odour might be construed as odd since the odour is presented out of context (i.e. the perception of a perfume-base in an ERP experiment rather than in normal social interaction). The odours in the present study, however, were selected as familiar stimuli which subjects would not find difficult to process. These odours were presented at suprathreshold concentration, were detectable, identifiable and were familiar. The odour of galaxolide may have been only faintly detectable, be relatively unfamiliar and would certainly have been unidentifiable to untrained subjects. Thus it is possible that this odour might have generated less distraction as a result of its "simple", possibly non-lexical, characteristics. The odours used in the present experiment, detectable and familiar stimuli, may have exerted a different effect to that of a synthetic musk due to their "psychological" complexity.

*5.9.iv. Was any diurnal variation apparent for any component?*

Although not specifically designed to demonstrate the effects of time-of-day, the nature of the present experiment allowed the observation of any diurnal variation which might exist within the three hour period extending over the lunchtime period. Previous

studies of human performance have suggested that human performance at this particular time of day (midday) may vary significantly (Folkard, 1982).

The expected fluctuations in P300 amplitude were not observed and neither was any temporal alteration in N100 amplitude obtained. The P200 to standard stimuli, however, was significantly affected by the time-of-day factor, showing significantly greater amplitude during the afternoon session than in the morning at C4. The amplitude of the P200 was also significantly greater at F3 during afternoon exposure to vegetable than during morning exposure.

Although P300 amplitude appeared to show no diurnal fluctuation, P300 latency was significantly longer at F3 in the afternoon than in the morning. As for P300 amplitude, there was no significant interaction between group and time-of-day. Previous effects of time-of-day and food ingestion on P300 latency have been modest (Geisler & Polich, 1992 a, b; Pietrowsky *et al*, 1989) and the effects of odour of latency have not been considered (Lorig *et al*, 1991). Polich (1986), however, reports increased latency when ignoring stimulus items when compared with actively discriminating between them. One possible explanation for the longer latencies in the afternoon is the subjects' attention decreased during the second session, perhaps due to familiarity with the testing protocol. Polich (1989) has also reported longer latencies with repeated presentation, although these latency effects were not particularly robust or significant. The one hour interval inserted between the two testing session in the current experiment, however, would suggest that slower latencies as a result of repeated presentation is unlikely. Increases in P300 latency have been observed in retardation (Squires, Galbraith & Aine, 1979) and dementia (Brown, Marsh & LaRue, 1982; Polich, Ehlers, Otis, Mandell & Bloom, 1986); shorter latencies have been associated with impaired memory performance (Howard & Polich, 1985). Given the bewildering

array of contexts in which alterations in P300 latency may be observed, perhaps the significance of this measure is questionable. The latencies for target N100 and P200 also showed inter-session effects. The N100 latency at P3 during exposure to vegetable odour was also larger in the afternoon than in the morning. Latency for N100 was longer in the afternoon than in the morning whereas P200 latency was shorter in the afternoon than the morning. A steady overall decrease in P190 latency over the day has been reported (Kerkhof, 1982) which appears to confirm the finding reported here.

## ~CHAPTER 6~

### **EXPERIMENT 2: MEAL CONSUMPTION, EXPOSURE TO FOOD ODOUR & EEG ACTIVITY-AN INVESTIGATION USING BRAIN ELECTRICAL ACTIVITY MAPPING. METHOD & RESULTS.**

#### EXPERIMENT 2

##### *6.1. Introduction.*

The results of experiment one confirmed that exposure to certain odours modifies specific components of the averaged evoked potential. Some of these modifications appear to be related to the psychometric properties of the odour, particularly the odour's hedonic quality. Significant, if unexpected, effects of meal ingestion were also obtained with the lunch group showing larger amplitude P200 than the no-lunch controls. The odour of vegetable was also associated with shorter P200 amplitude in the unfed group in the second recording session. No negative olfactory alliesthesia was found.

The nature of the evoked potential is to give a gross electrophysiological measure of exogenous and endogenous behavioural processes. The endogenous processes, reflected in the P300 and to a lesser extent, the P200, largely comprise cognitive processes such as decision-making or, more parsimoniously, context-updating since these have been the types of cognitive processes thought to be reflected in late positive going-waves (Ritter, Vaughan & Simson, 1983; Hillyard, 1984). Exogenous components, as reflected in early negative components, largely reflect sensory responses which would not normally be measurable, electrophysiologically, by other psychophysiological techniques. The evoked potential is a useful way of demonstrating the effects of external variables on sensory and cognitive processing. They are, however, event-locked and require special experimental paradigms in order for them to be elicited. Recording of the "spontaneous" EEG presents neither of these problems. Although experimental manipulations and EEG recording are often synchronised, studies exploring EEG concomitants of human performance determine the effects of particular variables on normal, on-going EEG behaviour, using stimuli which are not often susceptible to the EP recording approach.

Effects of odour on the EEG, as reviewed in an earlier chapter (**Chapter 4, sections 4.10., 4.12-14.**) have been noted in a number of studies although the findings are often contradictory (e.g., Lorig & Schwartz, 1988; Lorig *et al.*, 1988; Klemm *et al.*, 1992). The number and type of odours used in these studies have ranged from three (Lorig & Schwartz, 1988) to seven (Klemm *et al.* (1992) and from perfumes (Lorig & Schwartz, 1988) and essential oils to common odorants (Klemm *et al.* 1992). No EEG study designed to elicit changes in the EEG as a result of exposure to odour have explored the possibility of utilising food odour, a common, familiar and affectively potent stimulus. Food odour may, in fact, be construed as more affectively weighed than other pleasant/unpleasant odours not simply due to the subject's immediate

response to a sweet or savoury-smelling food odour but also due to the experience with that odour in the past (Lawless, 1991a). A small number of studies have suggested changes in the affective rating of food odour after the ingestion of a meal, for example, although the experiment reported in **Chapter 5** found no meal-related changes in the pleasantness ratings of the food odours used. Recent studies (reviewed in **Chapter 4**, sections 4.14-16.) suggest that the affective response to a stimulus may be reflected in EEG hemispheric asymmetries (e.g., Ahern & Schwartz, 1985; Davidson, 1984; 1988; 1992; Jones & Fox, 1992; Tomarken *et al*, 1992; Wheeler *et al*, 1993). These studies normally employ visual stimuli that are rated by the subject for their affective content (does it make the subject happy, disgusted, sad, angry? etc). The EEG recorded during exposure to those stimuli (usually a film or video) eliciting the most intense emotional response is "flagged". Asymmetries have been found for both negative and positive emotional stimuli with increased left anterior hemispheric alpha activation for positive stimuli and increased right anterior hemispheric alpha activation for negative stimuli. Other, inconsistent waveband changes have also been reported (see **Table 4b**, **Chapter 4**).

In view of the hedonic component of odour and its ability to produce marked emotional responses of pleasure and disgust (see **Chapter 2**), similar affective asymmetries may be generated by olfactory stimuli if one accepts the assumption that the two senses- vision and smell- are equipotential in this context. There are significant, self-evident differences in the structures and operations of the visual and olfactory systems (Kandel & Schwartz, 1987). The cognitive processing of each type of stimulus may also be dissimilar (Serby & Chobor, 1992). If, however, EEG asymmetries occur to affective stimuli, regardless of the sensory modality which transmits them, then odour and films should both generate the pattern already reported for visual stimuli. Some authors have argued that the affective asymmetries found represents the electrophysiological

representation of withdrawal and approach behaviours (Davidson, 1984; 1992; Davidson, Ekman, Saron, Senulis & Friesen, 1990). In view of odour's role as a caveat and attractant (as reviewed in **Chapter 2**), this stimulus would seem to be a potentially effective elicitor of these two types of behaviour.

Also noted in **Chapters 3 & 5** was the potential for the rating of a food odour to change after ingesting a meal. Evidence from **Chapter 5** suggests that this finding is not robust. It was noted, however, that the range of odorants used may have been of limited usefulness to the experiment. In the present study, the psychometric procedure is modified to include both pre- and post-prandial ratings of the odours specifically in order to account for time-of-day effects (which may have influenced the results of experiment one). More importantly, the range of food odours is also extended. If previous studies are correct in concluding that the affective response to odour changes post-prandially, and if the affective response to smell affects the EEG in a similar way to that of a picture or photograph, then hemispheric asymmetries could be expected post-prandially: fed subjects would be expected to show less left anterior alpha activation than unfed controls. Alternatively, fed subjects may show increased right anterior alpha activation if the odours are rated as less pleasant.

## METHOD

### *6.2. Subjects.*

Subjects comprised 21 right-handed, non-smoking students at the University of Warwick plus respondents to a feature in a local newspaper distributed in the Coventry area. Individuals had been pre-informed that the experiment was designed to investigate the effects of food odour on brain activity. Age ranged from 17 to 37 years.

Handedness, anosmia and discrimination ability was assessed as in experiment one and instructions for the preparation of the experiment (e.g., food consumption, health, use of perfumed products) were identical to those in experiment one. The group was divided into two conditions. Group 1 (N=12; 5 male, 7 female) received a prescribed lunch in-between two testing sessions (Lunch Group); Group 2 (N= 9; 2 male, 7 female) did not receive lunch but remained in the laboratory under experimental supervision (No-Lunch Group). The data from one subject in the lunch group were rejected due to high levels of artifact. For EEG data purposes, this group thus contained 11 subjects (5 male, 6 female).

### *6.3. Procedure.*

Subjects were tested individually and entered the laboratory at either 11 a.m. or 12 noon when the olfactory discrimination task and a handedness questionnaire were administered. Electrodes were applied as in experiment one. Following electrode application, subjects were led into an olfactorium where they were told that the aim of the experiment was to investigate the brain's response to food odour. They were further told that they would receive a number of trials, lasting approximately one minute, during which they may or may not be able to detect an odour. They were told not to expect an odour to be present at every trial (this proviso was included in order to avoid false hits). Occluded goggles were used to prevent extraneous visual cueing and head-phones emitting soft "white" noise were worn to reduce external auditory interference. In order to reduce eye artifact, subjects were instructed to keep their eyes closed during each of the trials but were told that they would be free to move about after the completion of each trial. Instructions regarding movement and respiration were the same as in experiment one.

When subjects were comfortable EEG recording began, with a blank (control) always presented at the first trial, as a baseline measure. Seven odours were presented, in counter-balanced order, with a 1-minute inter-trial interval in order to allow the dispersal of the previous odour. An extractor fan was in operation to facilitate the dispersal of the odour. Following the first testing session, all subjects were led back into the laboratory and completed a psychometric rating test. This involved rating the seven odours to which they had been exposed in session one along five dimensions: pleasantness, strength, familiarity, trigeminal and alertness using 12.5 cm. bipolar Lickert-type line scales. The dimensions represented were pleasant (0 cms)-unpleasant (12.5 cms), weak-strong, unfamiliar-familiar, stinging-soothing and relaxing-alerting. Subjects were told not to spend too long rating any one odour. A further psychometric-a hunger rating- was included at the end of the odour ratings. This test also involved placing a mark along a 12.5 cm. line-scale, with "very hungry" representing one pole (0 cms) and "not at all hungry" (12.5 cms) the other (see **appendix B3**).

After completion of the psychometric ratings, Group 2 remained in the laboratory for approximately thirty minutes. Group 1 was led away for a prescribed lunch which was of approximately thirty minutes duration. After this interval, subjects again completed a hunger rating test and were prepared for the second session of EEG testing. The procedure for this second session was identical to that in session one. After completion of the second EEG session, subjects underwent the same odour rating exercise completed after session one. Subjects were then debriefed, paid and received a free brain-map.

#### **6.4. The odours.**

The odours differed slightly from those in experiment one for two reasons. In order to determine any effect of odour valence on the EEG, the number of odours was increased

to include those that represented the odours of sweet and savoury foods. Pilot testing indicated that some of these odours would be perceived and rated as more pleasant than others. Thus a broader range of odorants was included in this experiment. The second reason is closely tied to the first. Previous investigations of EEG response to odour have chosen to present relatively few odours (see **Table 4a** in **Chapter 4**). Few of the stimuli used have been food odours. The odours selected for this experiment reflected a broad range of food odours and were used to determine whether the EEG responds to olfactory stimulation in a general fashion (a "blanket", sensory response) or whether it responds differentially to different odours (a "specific", perceptual response).

Two microlitres each of chocolate (chocolate flavour, 100%), spearmint (10% in DEP), almond (10% in DEP), strawberry (10% in DEP), vegetable (100%), garlic & onion (100%) and cumin (cumin seed oil, 100%) odour were used. All odorants were liquid concentrates and supplied by Quest International. Odorants on strips were sealed in a test tube until the time of the experiment and were re-prepared at the beginning of each week in order to avoid diffusion and tainting. The choice of odours reflected the sweet-savoury dimension of food aroma and were selected on the basis of food odorants which were commercially available. The vegetable odour was also selected for its unpleasantness (as demonstrated in experiment 1) and was used as an olfactory analogue of a generally unpleasant visual or auditory stimulus in order to examine any hemispheric EEG asymmetries in olfactory-emotional response. All odours were delivered on perfumers' strips and were presented approximately 7 cms. from the midline of the subject's face.

### **6.5. *The lunch.***

Lunch for Group 1 comprised a starter of vegetable soup (Heinz, 210g) followed by baked potato (400g) with baked beans (Tesco, 220g). A cup of carbonated mineral water (140 ml) was supplied as liquid refreshment. All cooked meals were prepared as described in experiment one.

### **6.6. *EEG apparatus and recording protocol.***

EEG activity was recorded in real-time from 28 electrode sites according to the 10/20 international placement system using a Neuroscience Brain Imager Series 3 model and referenced to linked ears. Each of the 5 classical EEG frequency bands- delta (0-3Hz), theta (4-7Hz), alpha (8-12Hz), beta I (13-22Hz) and beta II (23-30Hz) was monitored and recorded. Recording was undertaken at 256 microvolt sensitivity. The incoming EEG waveform is represented by 4096 values. With the 256 microvolt dynamic range, an accuracy of 256/4096 or 1/16 uV is obtained. Filters were set at default settings (0.3 Hz & 40 Hz). A Fast-Fourier Transform algorithm decomposed the raw EEG into the classical bandwidths at the rate of a 100 samples per second. This operation enables the display and storage of the relative amplitude for each of the frequencies (see **Appendix C2**).

The EEG is recorded as 2.56 seconds of averaged EEG activity (epochs). Power ( $\mu V^2$ ) in each frequency band is calculated for each epoch. Imager software calculates the amplitude for each electrode by taking the square root of the power. Data from each electrode site are taken to determine the voltages between electrode points (via a 4-point interpolation routine). Activity within this averaged epoch is consequently represented in visual form as the topographic map. A numerical value (in microvolts) is also obtained for each electrode site in each frequency band. The sampling rate is normally

twice the maximum frequency studied [the Nyquist frequency, Johnson (1980)]. Details of the brain imaging system are given in **Appendix C1**.

15 frames of no odour were recorded followed by 15 frames when the odour was present. A further fifteen frames were recorded post-odour where no smell was present. During the blank condition, 45 frames of no-odour were recorded. The aim of recording the first set of frames was to accustom the subject to the experimental setting and to enhance the feeling of relaxation. The final set of fifteen frames was used in order to allow the odour time to dissipate (the blank condition employed this condition in order to keep all trials time-constant) and to allow the subject's nose to recover from possible olfactory fatigue. Records were visually inspected for artifact employing a technique recommended by Neuroscience. Records showing significant amounts of symmetrical theta or delta activity in frontal leads were removed from the subject's overall EEG record. Those frames remaining were used in subsequent analysis. All artifact detection was made blindly, i.e., without knowledge of which record represented which odour condition.

## **RESULTS**

### ***6.7. EEG data reduction.***

EEG data from nineteen electrodes were used for subsequent analysis. These electrodes were selected on the basis of previous studies which have shown odour- and affect-specific responses at these sites (see **Tables 4a & 4b** in **Chapter 4**). The electrode locations represented broad delineations of lobe area: frontal (F3, F4, F7, F8, FZ), temporal (T3, T4, T5, T6), parietal (P3, P4, PZ), occipital (O1, O2) and central (C3, C4, CZ) [see **Fig. 6**]. In addition to the theoretical parsimony of reducing the

LEFT

RIGHT

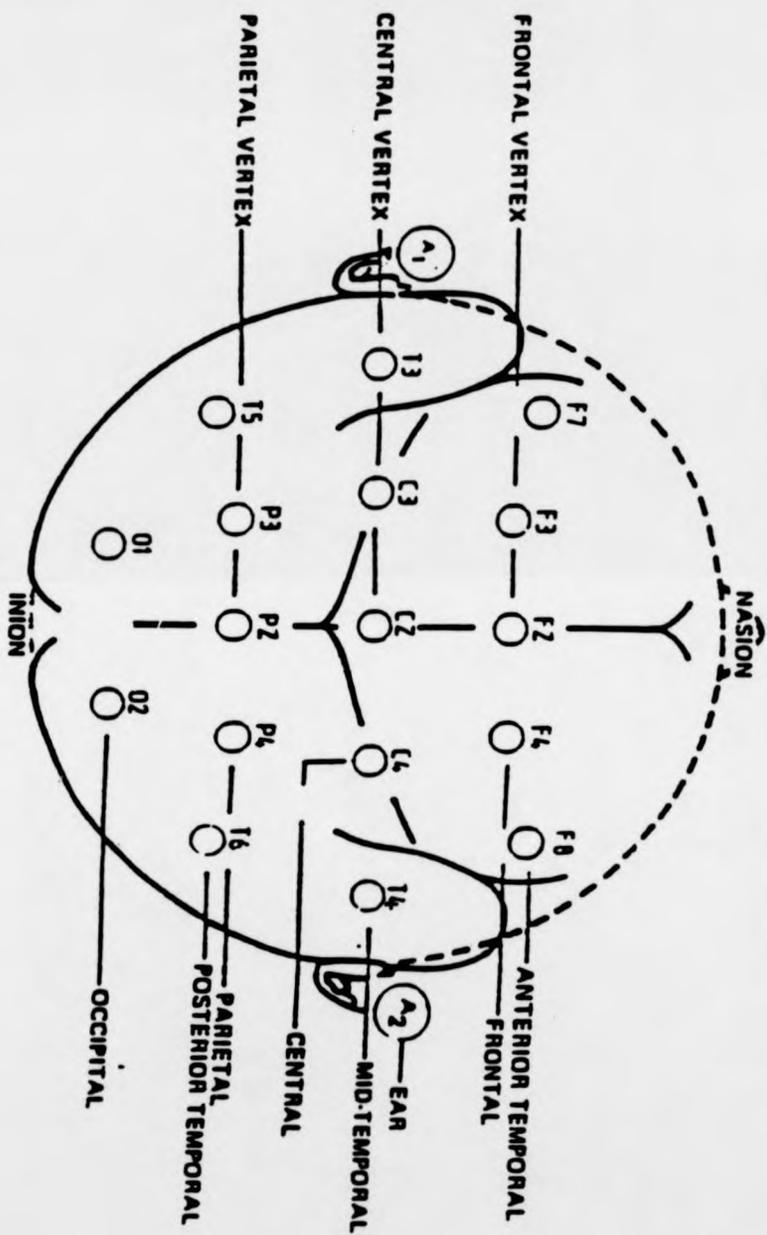


Fig. 6. Electrode array used for analysis in experiment two.

number of electrodes and selecting them judiciously, there is also the statistical advantage of avoiding p-inflation (see Section 4.5., Chapter 4) since large quantities of EEG factors (such as electrode site) would certainly weaken the power of an analysis of variance.

Data from each electrode in each waveband were downloaded from the Brain Imager to a Macintosh hard disk using the Autoedit 4.1.2 downloading programme (Milligan, 1992).

One method of data reduction in experiments in which variables are numerous is to create a simple macro programme which can be tailor-made to perform some specific reductive function such as averaging or summing. This task is effectively undertaken in SYSTAT (SYSTAT, Inc., 1992) by typing in the macro in the command editor window. This manual procedure, however, is time-consuming and arduous since it permits the submission of only one file at a time: alterations to the macro may have to be made for each successive file.

To combat this wasteful expenditure of time and energy a programme compatible with the SYSTAT statistical package was designed using SYSTAT software and Hypercard 2.0v2. "Systat Batch Commander" allows multiple files to be processed sequentially and automatically (hence "batch") using a single command file (Milligan & Martin, 1994; see also **Appendix D**). This programme rapidly converts the EEG data into a form suitable for analysis in SYSTAT. Imported and edited files were log transformed in order to avoid skewedness and to remove nonstationary variability such as increasing variance across time. The transformed data then underwent a repeated measures analysis of variance. Each electrode was analysed separately using an odour x group x time-of-day mixed design in the first instance.

## 6.8. Psychometric results.

### 6.8.i. Odour identification.

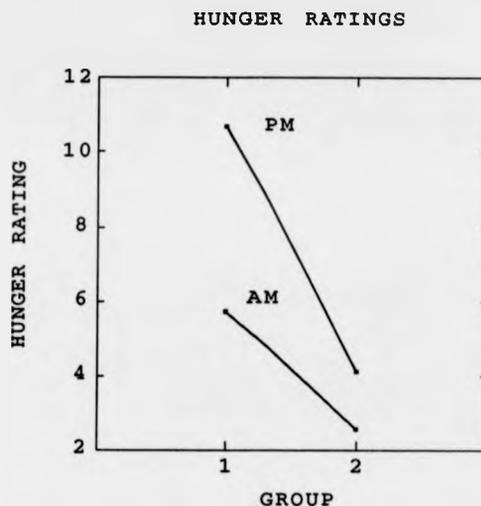
The procedure for the correct classification of odour was as described for experiment one. A post-hoc sign test revealed significant differences in the identifiability of some odours. Spearmint was identified by more people than was cumin ( $p=0.039$ ), strawberry (0.022), garlic and onion ( $p=0.013$ ) and almond (0.039). Furthermore, more people identified the vegetable correctly than they did garlic and onion ( $p=0.021$ ). The odours, ranked for identifiability and familiarity, are presented in **Table 6a**.

**Table 6a.** Identification of odours (from most to least well identified) and familiarity of odours (from most familiar to least). Means for familiarity are given with standard deviations in brackets.

Identification	Familiarity
Spearmint	Spearmint 10.96 (1.56)
Chocolate	Cumin 10.25 (1.74)
Vegetable	Almond 10.17 (2.50)
{Cumin	Chocolate 9.26 (2.67)
{Almond	Strawberry 8.92 (3.06)
Strawberry	G & O 8.9 (2.85)
Garlic & Onion	Vegetable 8.22 (3.21)

**6.8.ii. Hunger ratings.**

The data from the hunger rating scales were submitted to a two-way analysis of variance with group as the between subjects factor and time-of-day as the within subjects factor. There was a significant main effect of group [ $F(1,19)=21.51$ ,  $p<0.001$ ] and time-of-day [ $F(1,19)=21.17$ ,  $p<0.001$ ] as well as a significant interaction between the two [ $F(1,19)=5.95$ ,  $p=0.025$ ]. Post-hoc Tukey's tests showed that the results were largely due to differences between the a.m. and p.m. responses of the Lunch group and differences between this group and the control group for the p.m. ratings. Predictably, the lunch group gave a significantly higher rating in the afternoon than in the morning ( $df=19$ ,  $p<0.001$ ), a finding which attests to the satiating effect of the prescribed meal. There was no significant difference between the a.m. and p.m. hunger ratings of the control group, indicating that their hunger rating was relatively stable (a.m.=2.52, p.m.=4.07). This stability in the control group and the alterations in the lunch group are seen in **Fig. 6.i**.



*Fig. 6. i. illustrates a.m. and p.m. differences between the lunch (Group 1) and control groups' (Group 2) hunger ratings (0=not at all hungry; 12.5=very hungry). A clear difference can be seen between the lunch group's a.m. and p.m. rating and between the lunch and control groups' p.m. rating.*

There was no significant difference between the two groups' a.m. rating response (Lunch Group=5.68, Control Group=2.52) thus confirming that both groups were initially of similar "nutritional status". The groups' p.m. ratings differed significantly, however, with the Lunch group giving a higher rating (i.e. indicating feelings of less hunger) than did the controls ( $df=33$ ,  $p<0.0005$ ).

**6.8.iii. Psychometric ratings: pleasantness, strength, familiarity, trigeminal and alertness.**

**(a) Did the ingestion of lunch affect any of the psychometric ratings?**

Data from each of the psychometric dimensions were submitted to a repeated measures, three-factor analysis of variance with group as the between subjects factor and odour and time-of-day as the within subjects factor. No three-way interaction was obtained for any dimension nor was there a main effect of time-of-day.

**(b) Did the odours differ significantly on any of the dimensions?**

The means and standard deviations for each dimension and odour are given in **Table 6b**.

**(b) i. Pleasantness.**

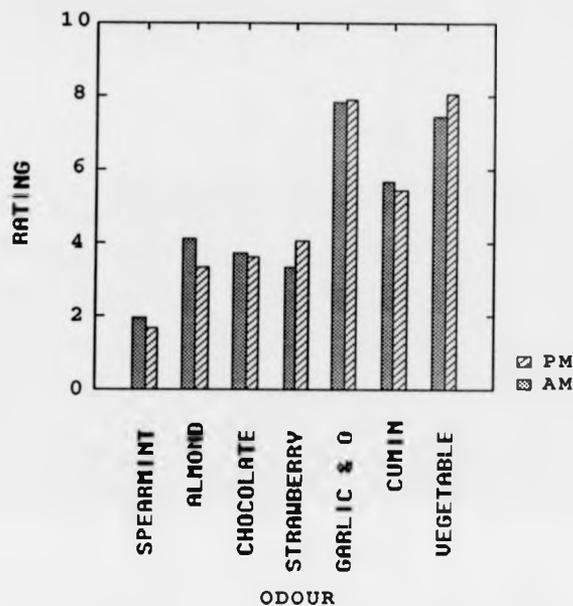
Pilot testing had indicated that the vegetable and garlic and onion odours were rated more unpleasant than other food odours tested. In fact, the present analysis demonstrated significant differences between the odours along this dimension [ $F(6, 108)=11.61, p<0.00001$ ]. **Fig. 6.ii.** illustrates these differences more clearly. Post-hoc paired samples t-tests revealed that spearmint was rated as more pleasant than strawberry ( $t=4.51, df(19), p<0.001$ ) or cumin ( $t=4.62, df(19), p<0.001$ ). The garlic and onion odour was rated as less pleasant than spearmint ( $t=5.93, df(19), p<0.001$ ) or chocolate ( $t=4.23, df(19), p<0.001$ ) with a trend towards significance for garlic-almond ( $t=3.46, df(19), p=0.003$ ) and garlic-strawberry ( $t=3.45, df(19), p=0.003$ ).

**Table 6b.** Odours ranked for pleasantness (most pleasant to least pleasant), strength (strongest to weakest), familiarity (most familiar to least), trigeminal stimulation (stinging to soothing) and alertness (most alerting to most relaxing). The table shows means with standard deviations in brackets.

Pleasantness	Strength	Familiarity	Stinging-Soothing	Alerting-Relaxing
Spear. 1.82 (1.46)	Cumin 12.77 (9.29)	Spear. 10.96 (1.56)	G & O 4.72 (2.27)	G & O 3.56 (4.5)
Choc. 3.66 (3.02)	Spear. 10.7 (1.39)	Cumin 10.25 (1.74)	Cumin 5.07 (2.82)	Cumin 4.81 (2.58)
Strawb. 3.68 (2.23)	G & O 10.57 (1.47)	Almond 10.17 (2.5)	Veg. 5.77 (2.58)	Veg. 5.18 (2.34)
Almond 3.72 (3.45)	Veg. 10.26 (1.61)	Choc. 9.26 (2.69)	Strawb. 7.1 (2.53)	Almond 6.4 (3.1)
Cumin 5.55 (3.5)	Almond 9.32 (3.35)	Strawb. 8.92 (3.06)	Almond 7.58 (3.13)	Strawb. 6.48 (2.52)
Veg. 7.74 (3.22)	Choc. 9.26 (2.26)	G & O 8.9 (2.85)	Choc. 8.2 (2.46)	Choc. 7.37 (3.19)
G & O 7.76 (3.79)	Strawb. 8.97 (3.1)	Veg. 8.22 (3.21)	Spear. 9.4 (1.92)	Spear. 7.47 (3.19)

**KEY:** Choc.=Chocolate, G & O=Garlic & Onion, Spear.=Spearmint, Strawb.=Strawberry, Veg.=Vegetable

## PLEASANTNESS RATINGS FOR ODOURS (AM VS PM)



*Fig. 6. ii. illustrates differences in the pleasantness ratings for all odours grouped by a.m. and p.m. (0=pleasant; 12.5=unpleasant). Although there are clear differences between odours, there appears to be little effect of lunch on pleasantness ratings.*

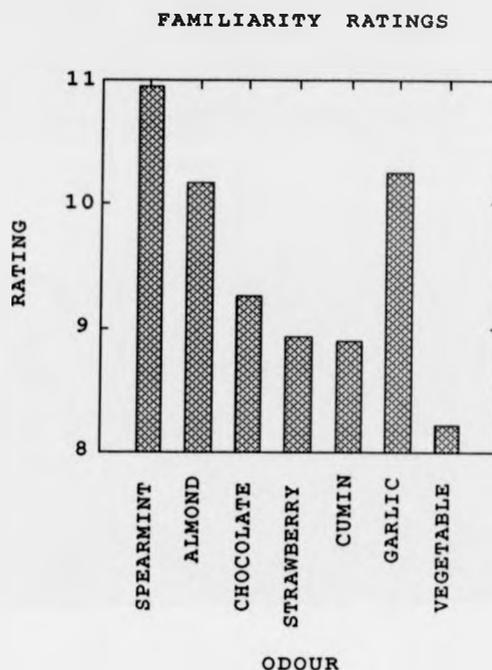
Further significant differences in pleasantness were found with the vegetable odour which was rated as significantly less pleasant than spearmint ( $t=7.21$ ,  $df(19)$ ,  $p<0.001$ ), almond ( $t=3.96$ ,  $df(19)$ ,  $p=0.001$ ), chocolate ( $t=4.15$ ,  $df(19)$ ,  $p=0.001$ ) or strawberry ( $t=4.13$ ,  $df(19)$ ,  $p=0.001$ ).

*(b) ii. Strength.*

There were no significant main effects of odour on strength, indicating that the odours, although delivered at suprathreshold strength, were isointense. No significant effect of group or time-of-day was observed and no significant interactions were obtained.

*(b) iii. Familiarity.*

There was a significant main effect of odour on familiarity [ $F(6,102)=3.68, p=0.009$ ] but this effect was restricted to the vegetable odour which was rated as less familiar than spearmint ( $t=4.03, df(20), p=0.001$ ). **Fig. 6.iii.** illustrates the relative differences between the odours on this dimension. There were significant trends, however, with the vegetable, again, being rated less familiar than cumin ( $t=2.91, df(19), p=0.009$ ) and spearmint being rated more familiar than strawberry ( $t=2.94, df(20), p=0.008$ ). The familiarity of spearmint in these examples appears to reflect the finding in **section 6.8.i.** where it was identified more correctly than other odours. There were no other significant effects or interactions.

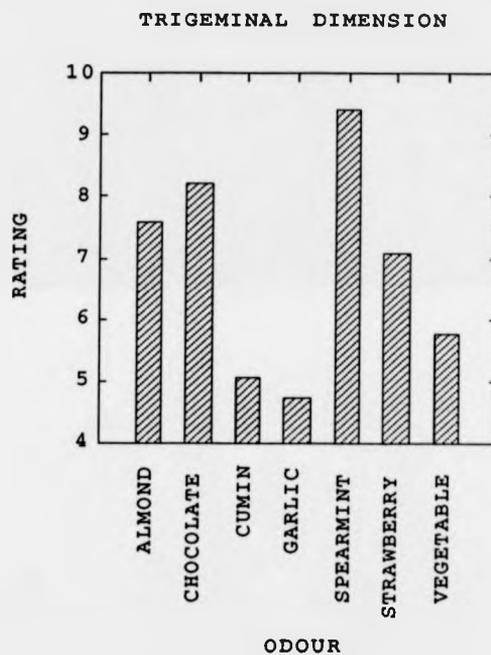


*Fig. 6. iii. illustrates differences between odours on the familiarity dimension. (0=unfamiliar; 12.5=familiar).*

*(b) iv. Stinging-soothing.*

There was a significant effect of odour for the trigeminal dimension [ $F(6, 98)=8.5$ ,  $p<0.00005$ ]. Post-hoc comparisons revealed marked differences between garlic, vegetable and cumin with the other odours, as illustrated in Fig. 6.iv. Spearmint was rated as more soothing than garlic and onion ( $t=6.16$ ,  $df(19)$ ,  $p<0.001$ ), vegetable ( $t=5.13$ ,  $df(18)$ ,  $p=0.001$ ) or cumin ( $t=5.48$ ,  $df(19)$ ,  $p<0.001$ ). Two further odours were rated as significantly different from vegetable, garlic and onion or cumin. Almond was rated as more soothing than garlic and onion ( $t=3.86$ ,  $df(19)$ ,  $p=0.001$ )

or cumin ( $t=3.97$ ,  $df(18)$ ,  $p=0.001$ ) while the chocolate odour was rated as more soothing than garlic and onion ( $t=5.04$ ,  $df(19)$ ,  $p<0.001$ ) or vegetable ( $t=3.94$ ,  $df(18)$ ,  $p=0.001$ ). The only other significant pairwise comparison was that between spearmint and strawberry where spearmint was rated more soothing than strawberry ( $t=3.68$ ,  $df(19)$ ,  $p=0.002$ ). No other main effects or interactions were obtained.



*Fig. 6. iv. illustrates differences between odours along the stinging-soothing dimension (0=stinging; 12.5=soothing).*

*(b) v. Alerting-relaxing.*

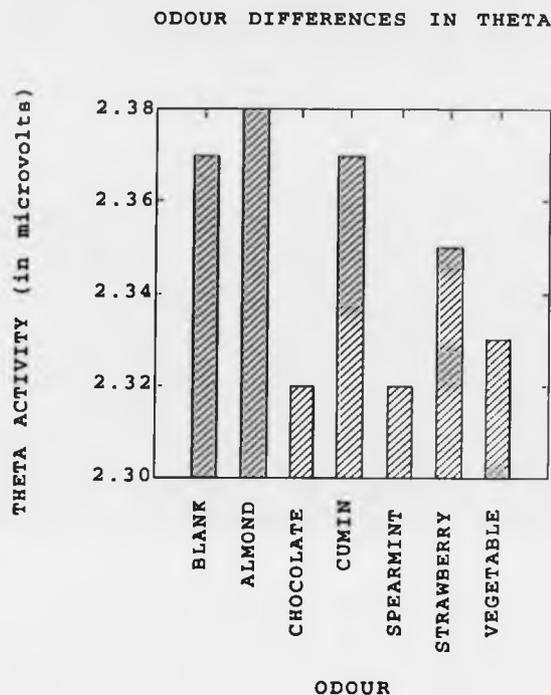
A significant effect of odour was also obtained on the alertness dimension [ $F(6, 108)=4.09, p<0.001$ ]. Post-hoc pair-wise comparisons showed that this effect was restricted to two pairs of odours: chocolate and garlic and onion ( $t=3.54, df(19), p=0.002$ ), and chocolate and vegetable ( $t=3.55, df(19), p=0.002$ ). In both examples, chocolate was rated as more relaxing than the other two odours a finding which, coupled with the results from the trigeminal ratings suggest that chocolate might have pronounced effects on mood. A positive correlation was found between ratings for chocolate on the trigeminal and alertness dimensions ( $r=0.885, p<0.001$ ). Similar correlations were found for the almond ( $r=0.898, p<0.001$ ), cumin ( $r=0.785, p=0.01$ ), vegetable ( $r=0.983, p<0.001$ ) and garlic and onion ( $r=0.733, p=0.05$ ) odours. Interestingly, there was also a positive correlation between the alertness responses of vegetable and garlic and onion ( $r=0.733, p<0.001$ ) which suggests that these two odours may represent similar positions along this dimension, a suggestion supported by the results of the post-hoc analysis.

*6.9. EEG results.*

The data from each of the EEG bands were submitted to a three-way repeated measures analysis of variance (odour x group x time-of-day).

*6.9.i Effects of odour.*

No significant main effect of odour was found for delta, alpha, beta 1 or beta 2. However, a significant main effect was found for the theta waveband [ $F(7,28)=4.39, p=0.022, G-G$  corrected]. This occurred at the right frontal region and was due to a difference between the spearmint and strawberry odours. Strawberry odour was associated with significantly greater theta than the odour of spearmint ( $t=4.22, df(6), p=0.006$ ), as illustrated in Fig. 6. v.



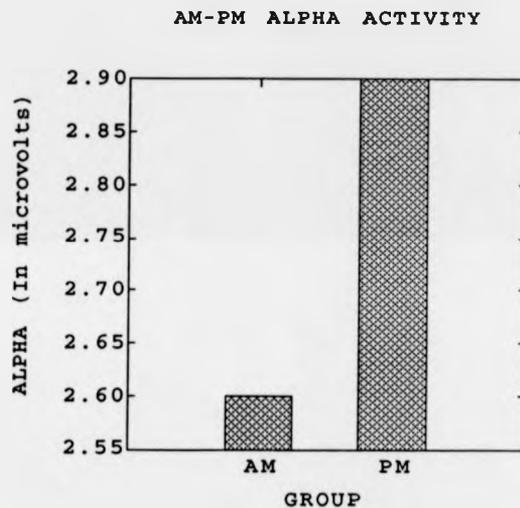
*Fig. 6. v. illustrates differences between odours in the theta frequency for electrode F8. A significant difference was found between spearmint and strawberry with the strawberry odour eliciting more theta than spearmint. EEG data are for theta (log).*

#### *6.9.ii Effect of group.*

There was no main effect of group at any site for any of the wavebands.

*6.9.iii. Effect of time-of-day.*

There was a significant effect of time-of-day at PZ for the alpha waveband [ $F(1,40)=8.47, p=0.044$ ] as seen in Fig. 6.vi. Activity in this band was greater in the afternoon session than in the morning session ( $t=3.2, df(5), p=0.024$ ). There were no other effects of time-of-day.



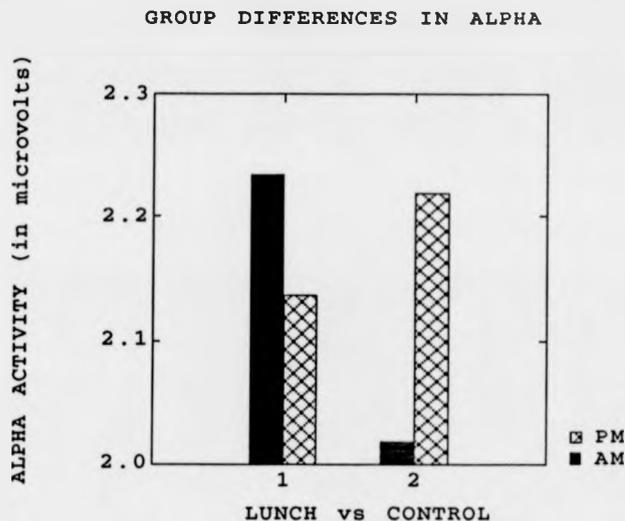
*Fig. 6. vi. illustrates time-of-day differences in the alpha frequency for the electrode PZ. Significantly more activity in this waveband was found in the afternoon session across both groups. EEG data are for alpha (log).*

*6.9.iv. Did odour interact with group or time-of-day?*

There were no odour x group interactions obtained, although a significant odour x time-of-day interaction for theta was obtained [ $F(7,28)=4.92, p=0.036$ ]. This effect was restricted to the vegetable odour which was associated with more theta during the morning session than the afternoon session ( $t=4.13, df(5), p=0.009$ ).

*6.9.v. Were any odour x group x time-of-day interactions obtained?*

To explore the possibility of EEG group differences in response to odour in the morning and afternoon, a three-way interaction would support any post-prandial changes if the effects were not restricted to the morning data alone. In fact, a significant three-way interaction was obtained for alpha but for no other waveband. This effect was present at the right anterior region (T4: [ $F(7,28)=5.05, p=0.022$ ]), and was due to the control group which showed less alpha activity in the morning than in the afternoon ( $t=6.97, df(3), p=0.006$ ), as can be seen in **Fig. 6.vii**.



*FIG. 6.vii. illustrates group differences in alpha for electrode T4. The control group appears to generate significantly more alpha activity in the afternoon than in the morning. EEG data are for alpha (log).*

*6.9.vi. Was EEG asymmetry apparent for pleasant, unpleasant and neutral odours?*

To explore the relationship between cerebral asymmetry and hedonic valence the log transformed data from eight electrode sites: left and right frontal (F3 and F4), left and right anterior (T3 and T4), left and right parietal (P3 and P4) and left and right posterior (C3-C4) were selected to give an asymmetry index (Log L-Log R). Thus a minus score would indicate greater right-sided activity while a plus score would indicate greater left-sided activity. This simple left-minus-right transformation is possible with log transformed data which avoid the use of fractioned indices. To facilitate subsequent analysis, 10 was added to the index in order to remove confusion over signs in the

software during statistical analysis. Alpha and theta wavebands were analysed, based on the results of previous investigations which demonstrated hedonic and hedonic-related EEG asymmetries restricted largely to these frequencies (see **Chapter 4, section 4.14.**).

*(a) EEG asymmetry and pleasantness.*

The results obtained from the psychometric data demonstrated highly significant differences in the pleasantness ratings of some odours. For the purposes of the asymmetry analysis, the most unpleasant and pleasant-rated odours were selected along with a neutral control (blank). The odours were spearmint and garlic and onion which represented the extreme ends of the pleasant-unpleasant spectrum. For the first analysis, all asymmetry indices for all odours were compared by region alone. This one way analysis of variance revealed no significant differences in left-right activity at any site in alpha (frontal: [F (2,28)=1.04, p=0.33]; temporal: [F (2,28)=0.85, p=0.42]; parietal [F (2,16)=0.37, p=0.63]; central [F (2,28)=0.83, p=0.43]) or theta (frontal: F (2,28)=0.51, p=0.58]; parietal: [F (2,28)=0.51, p=0.46]; temporal : [F (2,28)=0.39, p=0.68]). Asymmetry indices for both alpha and theta are displayed in **Table 6c.**

To examine possible changes in asymmetry between the control and lunch groups post-prandially, the data from the afternoon session were analysed separately using a repeated measures two-way analysis of variance. No main effect of odour was obtained but a significant main effect of group emerged for alpha at posterior sites [F(1,12)=7.2, p=0.02]. This effect was due to greater overall left posterior activity in the control group compared with the lunch group (asymmetry index for lunch group=9.87; control group=10.34). **Table 6d and 6e** show the F values and means for these asymmetries.

**Table 6c.** F values for pleasantness differences in asymmetry for a.m. data. Indices are based on the calculation  $\text{Log L-Log R} + 10$ . Standard deviations are given in brackets.

	ALPHA				THETA			
	S'mint	G&O	Blank	F	S'mint	G&O	Blank	F
<b>FRONTAL</b>	10.04 (.33)	9.94 (.13)	10.03 (.03)	1.04	9.98 (.18)	9.98 (.12)	10.02 (.22)	0.51
<b>TEMPORAL</b>	9.92 (.34)	9.84 (.29)	9.92 (.35)	0.85	10 (.27)	9.97 (.24)	9.97 (.24)	0.39
<b>PARIETAL</b>	9.72 (.45)	9.67 (.4)	9.72 (.46)	0.37	10.01 (.26)	9.97 (.19)	9.99 (.26)	0.68
<b>CENTRAL</b>	9.9 (.19)	9.87 (.22)	9.93 (.2)		--	--	--	--

S'mint=spearmint; G&O=garlic & onion.

**Table 6d.** F values and means for pleasantness differences in alpha asymmetry for p.m. data. Indices are based on the calculation  $\text{Log L} - \text{Log R} + 10$ . Standard deviations are given in brackets.

	S'mint	G & O	Blank	F		
				Odour	Group	Odour x group
<b>FRONTAL</b>						
(Lunch group)	9.98 (.04)	9.15 (.04)	9.96 (.033)	1.5	0.38	0.14
(Controls)	10.02 (.05)	9.98 (.05)	9.99 (.04)			
<b>TEMPORAL</b>						
(Lunch group)	9.94 (.13)	9.81 (.11)	9.92 (.12)	2.28	1.48	.06
(Controls)	10.12 (.15)	10.03 (.12)	10.12 (.13)			
<b>PARIETAL</b>						
(Lunch group)	9.94 (.06)	9.89 (.05)	9.98 (.05)	1.72	.93	.06
(Controls)	10.05 (.07)	9.96 (.06)	9.99 (.06)			
<b>CENTRAL</b>						
(Lunch group)	9.89 (.11)	9.84 (.09)	9.98 (.14)	1.12	7.2*	.07
(Controls)	10.34 (.12)	10.27 (.11)	10.35 (.17)			

\*  $p < .05$

**Table 6e.** F values and mean scores for pleasantness differences in theta asymmetry for p.m. data. Indices are based on the calculation  $\text{Log L} - \text{Log R} + 10$ . Standard deviations are given in brackets. Values for central electrodes are excluded due to missing data.

	S'mint	G&O	Blank	F		
				Odour	Group	Odour x group
<b>FRONTAL</b>						
(Lunch group)	10.00 (.06)	9.97 (.04)	9.98 (.04)	2.45	.02	.89
(Control)	10.05 (.07)	9.98 (.04)	9.94 (.05)			
<b>PARIETAL</b>						
(Lunch group)	9.95 (.05)	9.92 (.05)	9.92 (.04)	1.03	2.18	.36
(Control)	10.06 (.06)	10.01 (.05)	10.03 (.05)			
<b>TEMPORAL</b>						
(Lunch group)	9.99 (.12)	9.87 (.10)	9.98 (.12)	2.23	1.00	.65
(Control)	10.19 (.13)	10.05 (.12)	10.06 (.14)			

*(b) EEG asymmetry and electrode position.*

To explore possible differences in asymmetry by electrode position, each odour was analysed separately by electrode site (frontal, temporal, posterior and central). There were no differences in asymmetry across position for any odour in either alpha or theta. Using the p.m. data from the two groups as before, however, a significant effect of group emerged for the unpleasant (garlic and onion) odour [ $F(1,16)=10.46, p=0.005$ ] and the pleasant (spearmint) odour [ $F(1,15)=5.74, p=0.03$ ] in alpha. Both effects were due to greater relative overall left-hemisphere activity in the control group when compared with the lunch group (for garlic & onion: lunch group index=9.89; control group=10.04; for spearmint: lunch group index=9.87; control=10.10). There were no position x group interactions. F values for odour, group and position p.m. effects are displayed in **Table 6f & 6g** (see overleaf).

**Table 6f.** F values and means for position asymmetries (within region) in alpha and theta (a.m.). Indices were calculated as described in the text. Standard deviations are given in brackets. Central electrode data for theta are excluded due to missing values.

(a) ALPHA					
Odour	Fr.	Par.	Temp.	Cen.	F
<b>SPEARMINT</b>	10.02 (.33)	9.85 (.46)	9.85 (.35)	9.87 (.20)	1.11
<b>G&amp;O</b>	9.94 (.13)	9.82 (.45)	9.81 (.34)	9.88 (.19)	.89
<b>BLANK</b>	10.05 (.34)	9.85 (.4)	9.87 (.29)	9.88 (.22)	.69
(b) THETA					
<b>SPEARMINT</b>	9.97 (.18)	9.96 (.26)	9.96 (.27)	-	.02
<b>G&amp;O</b>	9.99 (.12)	9.95 (.19)	9.96 (.24)	-	.79
<b>BLANK</b>	10.00 (.22)	9.98 (.20)	9.95 (.24)	-	.44

Fr.=frontal; par.=parietal; temp.=temporal; cen=central.

**Table 6g.** F values and means for position asymmetry (within region) for alpha (p.m. only). Standard deviations are given in brackets.

Odours	Fr.	Par.	Temp.	Cen.	F		
					pos.	group	group x pos.
<b>SPEARMINT</b>							
(Lunch group)	9.91 (.12)	9.93 (.06)	9.82 (.11)	9.86 (.10)	.93	5.74*	1.07
(Control)	10.18 (.13)	9.97 (.08)	10.02 (.13)	10.24 (.12)			
<b>G&amp;O</b>							
(Lunch group)	9.96 (.04)	9.94 (.05)	9.8 (.09)	9.86 (.08)	1.72	10.46**	2.02
(Control)	9.99 (.05)	9.97 (.06)	9.99 (.11)	10.2 (.10)			
<b>BLANK</b>							
(Lunch group)	9.96 (.03)	9.98 (.05)	9.92 (.12)	9.92 (.12)	.16	1.63	.9
(Control)	9.99 (.05)	9.99 (.66)	10.12 (.11)	10.12 (.10)			

pos.=position (electrode)

\*=p<.05

\*\*=p<.01

**Table 6h.** F values and means for position asymmetry in theta (p.m. only). Standard deviations are given in brackets. Data for central electrodes are excluded due to missing values.

Odour	Fr.	Par.	Temp.	F		
				pos.	group	group x pos.
<b>SPEARMINT</b>						
(Lunch group)	10.01 (.04)	9.97 (.04)	9.97 (.10)	.51	.92	.65
(Control)	10.03 (.06)	9.99 (.04)	10.12 (.12)			
<b>G&amp;O</b>						
(Lunch group)	9.98 (.03)	9.95 (.04)	9.9 (.08)	.08	.99	.52
(Control)	9.98 (.04)	10.01 (.05)	10.01 (.10)			
<b>BLANK</b>						
(Lunch group)	9.98 (.04)	9.95 (.05)	9.98 (.12)	.43	.33	.59
(Control)	9.94 (.05)	10.06 (.06)	10.61 (.10)			

*6.9. vii. Were differences in EEG asymmetry evident for alerting vs calming vs neutral odours?*

To examine the possible relationship between alertness and hemispheric EEG differences, asymmetry indices for those odours rated least and most alerting were calculated using the same electrode positions as those examined for pleasantness. The most alerting odour was garlic & onion (3.56), the least alerting odour was chocolate (7.47). Asymmetries in the alpha and theta wavebands were examined.

*(a) Differences in asymmetry between odours.*

There was no main effect of odour on EEG asymmetry, neither was there an interaction between group and electrode position. A significant effect of group was obtained, however, in alpha at central sites [ $F(1,10)=6.18, p=0.032$ ]. This effect was due to greater relative overall right hemisphere activity in the lunch group compared with the control group (lunch group index=9.85; control group=10.05) and appears to reflect the respective asymmetries of both groups seen in section 6.9.vi.(b).

*(b) Differences in asymmetry by position*

There was a significant p.m. interaction between position and group for the chocolate odour in the theta waveband [ $F(2,30)=4.65, p=0.038$ ]. Post-hoc Tukey's tests revealed that this interaction was due to the control group which showed greater left-sided asymmetry in the temporal region (10.19) than the frontal (9.995) region ( $df=30, p<0.001$ ) and differences between the p.m. activity of the control and lunch group. The control group showed significantly greater left-sided asymmetry (9.86) in the temporal region (for chocolate) than did the lunch group (10.187); [ $df=42, p<0.001$ ].

A significant effect of group emerged for the blank condition in alpha [ $F(1,12)=7.27$ ,  $p=0.019$ ]. Here, controls again showed greater overall left hemisphere activity compared with the lunch group (lunch group index=9.93; control=10.05).

### *6.10. Discussion.*

#### *6.10.i. Did ingestion of lunch affect the hedonic ratings of food odour?*

As in experiment one, no effect of lunch were found for the post-prandial pleasantness ratings of food odour. The expanded range of odorants (which included the odours of both savoury and sweet foods) appeared to have no effect on selectively depressing post-prandial ratings. This second failure to replicate suggests that the phenomenon of negative olfactory alliesthesia may not be as replicable a phenomenon as its gustatory counterpart. In Cabanac's (1971) study using the odour of orange syrup, subjects rated this odour before and after a satiating injection of glucose. The decrease in pleasantness following the glucose infusion suggests that either (a) hedonic perception of food odour is genuinely related to the degree of satiety or (b) there is some special property of glucose that results in these depressed hedonic ratings. The first explanation does not appear to apply to the results reported here. Subjects receiving a meal gave significantly lower ratings of hunger after eating than before and responded significantly differently on this dimension from unfed controls. Thus, if lack of hunger is equated with satiety (and there there is a reasonable assumption that the two may be highly correlated), then the experience brought about by the lunch appears to mirror that of glucose. If, on the other hand, satiety is not equated with hunger and the two are measurably different states, then it is perhaps satiety or fullness rather than lack of hunger which results in post-prandial hedonic changes in food odour ratings. The possibility that fullness is a more accurate index of satiety than hunger is discussed in **Chapter 7**.

The second explanation, that glucose has specific properties which alter the hedonic perception of food taste and odour, is plausible. Subjects fed naturally are exposed to a number of different sensations-gustatory, olfactory, visual and tactile. An injection of glucose, however, removes the complex sensory experience of the meal beyond the subject's control. Food stimuli are regarded in isolation: there is simply a smell or a taste to rate in an artificially engineered affective state which the subject may, or may not find comfortable. It is arguable that in order for truly robust hedonic changes in olfactory rating to occur, it is necessary to use familiar but more salient food odours such as cooked food. Dueleaux *et al* (1973), for example, used such stimuli and reported significant post-prandial changes in hedonic ratings. It is possible, therefore, that the stimulus requires some form of perceptual or appetitive salience before negative olfactory alliesthesia may occur. This hypothesis is considered in more fully in **Chapter 7**.

#### *6.10.ii. The effects of odour on the EEG.*

In support of the findings of a number of other investigations, there were significant changes in the theta frequency as a result of exposure to odour. Significantly greater theta was evident for the odour of strawberry than the odour of spearmint at right frontal regions. Further, odour x time-of-day effects were found for the vegetable odour which was associated with greater theta in the morning than in the afternoon, regardless of the experimental group. No odour-related changes were found for alpha or beta.

The finding that strawberry elicited greater theta than spearmint in the right frontal region is similar to previous finding using spiced apple and lavender (Lorig & Schwartz, 1988). In the present experiment, the odour of spearmint was rated as significantly more pleasant and soothing than was that of strawberry, cumin, garlic &

onion or vegetable. In the Lorig & Schwartz (1988) study, spiced apple was associated with significantly less theta activity than was the lavender at right frontal and left posterior regions (Lorig & Schwartz, 1988). The authors also reported that the spiced apple odour was associated with self-reports of less tension and anxiety when compared with the lavender odour. In view of the self-reported responses to these odours, their effects on the theta frequency, and reports from others (Stacher *et al.*, 1979; Klemm *et al.*, 1992) it is arguable that the theta frequency is the waveband which is most susceptible to influence by exposure to odour and may be the dominant frequency for the processing of the affective properties of odour. This hypothesis, however, is not as clear-cut as it would appear. Although other authors have noted changes in theta as a result of exposure to odour (Stacher *et al.*, 1979; Lorig & Schwartz, 1988; Lorig *et al.*, 1990; Klemm *et al.*, 1992), changes have also been found in alpha (Lorig & Schwartz, 1988; Lorig *et al.*, 1991). As discussed in **Chapter 8**, these alterations in different bands may not be incompatible and are not unexpected. The association between the theta frequency and the perception of odour and the notion that this waveband represents the olfactory EEG channel is discussed and argued in **Chapter 8**.

The reduced theta amplitude to the vegetable odour in the afternoon is intriguing. Given the association between lowered theta and decreases in anxiety and tension, it is possible that the response to vegetable was mediated by the psychometric property of the odour. Vegetable was rated as significantly less pleasant than the odours of spearmint, almond, chocolate or strawberry, significantly less soothing than the odours of spearmint and chocolate and significantly more alerting than the odour of chocolate. One possible explanation for the EEG finding is that EEG theta was lower in the afternoon as a result of some form of affective habituation, i.e. the subject's response to the odour during the first session would have been immediate; the odour would have

been novel and, possibly, startling. In view of vegetable's rating for alertness, the likelihood that it was startling is likely. Experience of the odour during the second session, when the odour was not novel and the subject had become familiar with the experimental protocol might have resulted in reduced theta during this more "relaxed" session. Whereas the response during the first session might have been partly hedonic (perceiving the odour as unpleasant) and partly cognitive (trying to identify the odour), the response during the second session may have been more analytic. Alternatively, there is some evidence to suggest that greater involvement in cognitive and perceptual processing is associated with increases in theta activity (Basar-Eroglu, Basar, Demiralp & Schurmann, 1992). It is possible that subjects exposed to the odour of vegetable for the second time were inclined to pay less attention to the stimulus having become accustomed to its properties. In **Chapter 8**, the significance of attention and theta activity to olfactory information-processing is considered in more detail.

*6.10.iii. The effects of time-of-day.*

Significant increases in alpha activity were noted during the second testing session compared with that obtained during the first session. These effects were unrelated to exposure to odour or to the ingestion of lunch. Although not designed to explore the effects of time-of-day in any detail, the results appear to show, as have a number of psychological/performance studies that changes in behaviour occur across the duration of lunchtime (see, for example, Brown & Graeber, 1982). In the present experiment, an hour and a quarter separated the two testing sessions. That alpha changes were observed between these two points either illustrates the diurnal, rhythmic nature of alpha or reflects a greater variability in the stability of alpha. Previous studies have demonstrated robust inter-correlations between EEG alpha recorded at separate times (usually weeks) [Gasser, Bacher & Steinberg, 1985; Burgess & Gruzelier, 1993; Tomarken *et al*, 1993]. Others have reported circadian acrophases in sporadically

monitored EEG but with different temporal reference points to those of the present experiment (Gundel & Hilbig, 1983). Lowered levels of alpha are commonly associated with increased activation; increases in alpha have been interpreted as a decrease in underlying activation. It has been argued that those performance effects attributed to eating a lunch are in fact the result of circadian shifts at the time of day when lunch is eaten (Brown, 1982; Naitoh, 1982; Folkard, 1982). The results presented here would appear to support this hypothesis although to a limited degree. The confident demonstration of such effects would entail monitoring EEG across large time spans. This procedure would ensure that the effects obtained were genuinely related to time-of-day and not to some other factor such as familiarity and ease with the experimental setting which may be a strong confounding factor. Although ease should be apparent with changes in beta (Linke *et al.*, 1989), the present experiment reported no diurnal effects of beta. Even so, the consideration of other potentially important variables cannot be overlooked.

#### *6.10.iv. Effects of lunch.*

No significant effect of group was found in the present experiment which suggests that the ingestion of lunch has little effect on the pattern of EEG in any frequency. Odour x group x time-of-day interactions were also absent which again suggests that the pre-and post-prandial response to food odour changed little, in terms of the EEG. In view of the fact that no negative olfactory alliesthesia was reported either, the absence of a three-way interaction is not altogether unexpected. In experiment one, however, several changes in the P200 were observed as a result of ingestion of lunch. The lack of a similarly significant EEG finding here suggests that either the ERP method is a more sensitive measure of detecting metabolic changes or some other more psychological changes as a result of food ingestion (which it might be) or that the ERP is a more sensitive measure of cognitive/attentional processing than the EEG (which is

arguable). Others have reported differences in the amount of theta produced as a result of either saline infusions or infusions of CCK during exposure to the noise and smell of prepared and cooking food (Stacher *et al.*, 1979). As noted in **Chapter 4**, however, the ability to distinguish the effects of noise/infusion from those of the smell/infusion is difficult. It is also possible, of course, that CCK has different metabolic and EEG effects to that of conventionally ingested food and this possibility can not be disregarded. On the basis of evidence presented here, however, there is no support for an EEG signature for satiety.

*6.10.v. EEG asymmetry for pleasant and relaxing odours.*

There were no main effects of odour valence on EEG pleasantness asymmetry nor were there position effects obtained for any odour. The results suggest that the ability of odour to generate similar asymmetric EEG responses to visual stimuli in alpha is low. There was, however, a group x odour interaction with the control group demonstrating increased overall left-hemisphere alpha activity (i.e. less left hemisphere activation) to garlic and onion and spearmint. If the alpha frequency can be characterised as an index of wakefulness this result is unusual since it would be expected that hungry subjects (controls) might react more attentively than the lunch group to food odour. The fact that the control group showed no asymmetry for the blank condition suggests that the effect obtained here is odour-related and not the result of generalised increases in left hemisphere activity in the controls. It is possible that the decreased activation reflects the lack-of-attention of the controls. These controls also showed greater overall left central alpha activity than did the lunch group. They also showed overall greater left-hemisphere alpha activity than the lunch group. The implications of these results will be considered in **Chapter 8**.

The results from the alpha frequency data do not provide support for the notion that unpleasant and pleasant olfactory stimuli behave in a similar electrophysiological way to pictorial stimuli. Alpha, however, as noted earlier, has been shown to be poorly responsive to manipulation by odour. Those studies which do report odour-effects are very few (see **Chapter 4, section 4.10**). The majority of EEG studies examining cognitive and affective processes have utilised, to a large degree the visual and visual-imagery systems (see **Chapter 4, section 4.1**.) which do, to a large degree, affect the pattern of alpha activity (see **Chapter 4, section 4.7**.). In view of the effects of odour exposure in theta, this frequency might be expected to show asymmetries which alpha may not be 'sensitive' enough to detect. No effects in this frequency, however, were found for any odour.

The EEG findings reported above and elsewhere (Lorig & Schwartz, 1988; Klemm *et al*, 1992) suggest that the tension-releasing and anxiety-alleviating effects of odour might be mediated by, or be indicated by, changes in the theta frequency. Indeed, a group x region effect was found in the theta frequency for the chocolate odour, the stimulus rated as most relaxing. Here, greater left hemisphere theta was found at temporal than at frontal sites in unfed subjects. Furthermore, greater left-hemisphere theta was also found in the unfed group than the fed group at temporal sites. The hypothesis by Lorig & Schwartz (1988) argues that the greater the degree of theta, the less relaxing the odour. Thus, low theta is found with exposure to relaxing olfactory stimuli when compared with stimuli rated as significantly less relaxing. In view of the affective asymmetries reported elsewhere, the finding that less theta was found in the left frontal region suggests that odours of a particular hedonic valence are capable of generating within-hemisphere differences similar to those found with films of differing hedonic valence. These other studies show increased activation in the left frontal areas to pleasant films. It is possible that odour exerts its effects, as suggested above, via the

theta frequency. Furthermore, the relationship between the position effect reported and the psychometric property of the odour (relaxation) suggests that what may be measured in EEG studies using pictorial stimuli may not be the degree of happiness or pleasantness experienced but how relaxing (and unthreatening) the stimulus is. Since Davidson (1992) has suggested that approach-withdrawal may be reflected in EEG asymmetries, comfort with a stimulus and its acceptance might indicate a relaxation which is reflected by the left frontal increase in activity he and his colleagues have found. This hypothesis is considered in more detail in **Chapter 8**.

## ~CHAPTER 7~

### **EXPERIMENT 3: THE EFFECTS OF FOOD INGESTION AND THE ODOUR OF HOT, COOKED FOOD ON THE EEG. METHOD AND RESULTS.**

#### EXPERIMENT 3

##### *7.1. Introduction.*

The previous experiment demonstrated that simple food odorants were able to affect the pattern of the spontaneous EEG. The only EEG frequency which was significantly affected by exposure to odour was the theta waveband. Alterations in this frequency as a result of exposure to odour, as noted in section 6.10.ii. (Chapter 6), appears to be an electrophysiological characteristic of exposure to odour and would suggest that this frequency plays a special role in the mediation of olfactory experience, either at the sensory, perceptual or emotional end of information-processing. Time-of-day was also found to affect the EEG response significantly with greater alpha power found in the afternoon session than the morning session. The reason for this disparate diurnal response is unclear but may be related, as suggested in Chapter 6, to experimental familiarity or diurnal variation in the pattern of EEG alpha. It was also found that controls exhibited less alpha activity in the morning than in the afternoon. When activity was further analysed in terms of asymmetry, a group by position interaction for theta

demonstrated that the control and lunch group's p.m. EEG response to chocolate differed at temporal sites with the controls showing greater left-sided power than the lunch group. The controls also showed more left-sided temporal power to chocolate odour compared with frontal sites.

One of the aims of experiment two was to examine the possibility that exposure to odours of different valence would exert similar effects on hemispheric EEG activity (in terms of frontal/anterior asymmetry) to those reported with visual stimuli. These asymmetries in alpha, however, were not obtained although left hemisphere region differences were found with the most relaxing odour. Furthermore, the asymmetries expected from hungry subjects exposed to food odour were not found although in view of the finding that no negative alliesthesia was reported in fed subjects, the absence of an electrophysiological index of alliesthesia for any odour may not be altogether surprising. The controls, however, did show increased left-hemisphere alpha activity to both the pleasant and unpleasant odours, when compared with the lunch group.

One possible limitation of the stimuli used in experiment two (and, indeed, all other studies of odour and human EEG) is that the stimuli presented may not have the required ecological validity to produce affect-related effects in EEG alpha asymmetry, i.e., the stimuli used in this and other experiments may not have been perceived as natural odours but as synthetic compounds (which they were). Several subjects in experiments one and two commented on the "artificial" nature of some of the odorants used. In fact, all odours were manufactured by a food flavour company. Arguably, this may have been a plausible reason for the absence of any negative alliesthesia in those fed subjects exposed to food odour after eating. Furthermore, it would be instructive to examine the brain's response to a genuinely "biologically relevant" odour

that derives from source and is not a commercial analogue. It is possible, of course, that as long as the odours are rated as significantly pleasant or unpleasant, and brain responds to unpleasant and unpleasant smells in the same way it does pleasant and unpleasant films, then any asymmetries should be evident. There also exists the possibility that although rating scores for odours differ significantly on a pleasantness dimension, this does not necessarily imply that an odour can rightly be classified as "unpleasant". Its relationship with other odours is relative. Thus, a genuinely unpleasant odour-one scoring fairly highly on an pleasantness scale-should generate the affective asymmetries one would expect from an obnoxious stimulus. In view of the findings reported in experiment two, it is likely that EEG alpha may be responsive only to particular types of stimuli such as those considered relevant to approach and withdrawal. In short, it is arguable that more salient, distinctively approachable and repulsive olfactory stimuli are required before any such alpha asymmetry becomes apparent.

In experiment three, a similar experimental protocol to that of the second is employed. To determine the effects of genuine food aroma on the EEG, subjects will be presented with the odours of hot, cooked foods. The odours will also include those of foods eaten by the lunch group in order to establish a more rigorous test of alliesthesia and post-prandial EEG changes. As in experiment two, the relationship between EEG asymmetry and psychometric evaluation will be examined further. If the approach-withdrawal hypothesis of frontal EEG asymmetry is correct and if the assumption that pleasant or unpleasant odours exert the same effects on brain activity as do pleasant or unpleasant films, then odours customarily perceived as warning stimuli or those which alert, should produce an EEG pattern similar to that found with films rated as "disgusting", i.e. increased frontal/anterior right hemisphere alpha activation. One particular odour which meets the criteria of repulsion and the induction of withdrawal

behaviour is that of spoiled food (Janzen, 1977; Grey & Pearson, 1987). This is one of odour's functional characteristics: to warn of the danger of ingesting harmful food. In experiment three, the odour of rotting meat will be used as an evocative, unpleasant, withdrawal-behaviour inducing stimulus with the odour of a familiar, well-liked food used as the pleasant stimulus. In view of the realistic nature of the food odours used, it is expected that olfactory negative alliesthesia, if it does exist, would be evident. If the post-prandial alteration in rating for pleasantness is found, then it is fair to suggest that the lunch group's frontal/anterior EEG asymmetry may alter in accordance, with less alpha activation in the left frontal region and/or more theta activity generally evident.

### *7.2. Subjects.*

15 right-handed non-smokers (11 female; 4 male) from the University of Warwick plus readers of a local newspaper advertisement requesting subjects for an experiment on brain mapping and the sense of smell participated in the experiment. All subjects were screened for anosmia, odour discrimination, health and medication, as in experiments one and two. Following the first testing session, the group was randomly assigned to one of two conditions. Group 1 (4 female; 4 male) remained under laboratory supervision before the second testing session (No-Lunch group-control); Group 2 (7 female) received a prescribed lunch (Lunch group). All subjects gave informed consent.

### *7.3. The odours.*

The odours in the experiment were chosen to be representative of the odours of familiar, real and cooked food. Natural foodstuffs were prepared in the laboratory on the day of the experiment to ensure freshness and to avoid tainting. The odorants were baked beans (30g in a microwaveable plastic beaker), hot water (110 ml. in a microwaveable plastic beaker), coffee dissolved in hot water (110 ml. in a

microwaveable plastic beaker), chocolate (2 microlitres on a perfumer's strip) and rotting pork (1 inch cubed, in a plastic beaker, see below). The baked beans, hot water and coffee were heated in a 650 watt microwave oven according to manufacturer's instructions and were presented piping hot. In view of the possibility that any psychometric or EEG response to the heated beans and coffee may be mediated by trigeminal stimulation from the steam emitted, hot water was used as a control for the cooked foods.

The inclusion of the rotting pork determined whether the EEG responds to stimulation by an off-odour and whether the human EEG responds more differently to this than an odour considered more positively. The rancid odour of raw, decomposing or re-heated meat (including restructured meat) is the result of lipid oxidation (see Janzen, 1977; Gray & Pearson, 1987; Lillard, 1987; Sofos & Raharjo, 1989 for reviews). As tissue membranes are disrupted, exposure to oxygen causes the so-called "warmed-over-flavour" (or WOF, Tims & Watts, 1958). A number of factors affect the acceleration of lipid oxidation, including the amount of fatty tissue, the diet of the animal and lipid composition. Pork is one meat which rapidly oxidises and develops a rancid odour (more so than animal lipids with more saturated fatty acids). It also develops its WOF more rapidly when cooked. For this experiment, 1 inch squared of pre-cooked pork was allowed to develop rancidity for 1 week. It was kept in a sealed plastic container, wrapped in selophane and stored away in a laboratory cupboard until time for experimental preparation. This procedure was followed after consultation with food management agencies (Campden Food & Drink Research Association). Pilot testing confirmed the potency of the rancidity. Permission from the Departmental Safety Officer was obtained for the use of this stimulus.

The chocolate and baked bean odours were used to determine the response of the EEG to the odour of a food which the Lunch group had previously eaten. Although the cooked foods were prepared immediately before presentation, this preparation was undertaken well away from the subject. The olfactorium ensured that no pre-presentation food smells were detected and all subjects reported smelling no food odour before the actual presentation. To further ensure the odour-free integrity of the testing environment, all beakers containing food were sealed with a lid until the odour was presented.

All odours were presented in counter-balanced order but for the hot water which was always presented after baseline recording. The malodour was always presented last in order that its quality would not affect the perception of other odours. The stimuli were presented in their beakers (except for chocolate) about 7 cms from the midline of the subject's face.

#### **7.4. Procedure.**

Subjects were tested individually and arrived at the laboratory at either 11 a.m. or 12 noon. Testing was undertaken in two sessions separated by a 30-40 minute interval. Subjects had been instructed to eat no food, or ingest any caffeine for 3 hours prior to the experiment. Pre-experiment instructions were given as in experiments one and two.

EEG electrodes were applied as described in experiments one and two. The recording procedure was identical to that in experiment two but for one major variation (see section 7.6. below). Subjects were tested in the olfactorium as before and were given identical instructions to those in experiment two. A minor modification was made to the subject's conditions. Whereas in the previous experiment subjects wore headphones emitting white noise in order to preclude any extraneous auditory

stimulation, subjects in present study received no white noise and but did wear headphones. This modification ensured that subjects were distracted neither by the white noise or environmental noises.

Following the first testing session, subjects rated the odours they had smelled along various dimensions (see below). The odours of hot, cooked foods were presented in beakers (excepting chocolate which was presented on a perfumer's strip) beneath the subject's nose. Subjects had their eyes closed during each of the presentations. When subjects had received enough stimulation to enable them to make a rating, the odour was removed and subjects made their rating. This was made along 12.5 cm. Lickert-type line scales (as in experiment two) with the poles at 0 or 12.5. The dimensions represented were pleasant-unpleasant (0-12.5), weak-strong (0-12.5), familiar-unfamiliar (0-12.5), alerting-calming (0-12.5), makes me happy-does not make me happy (0-12.5) and makes me hungry-does not make me hungry (0-12.5). The order of the poles was reversed for each odour in order to avoid response set. In addition to the odour ratings, subjects also completed a similar analogue-scale rating relating to their nutritional state. These ratings took the form of two 12.5 cm. line scales representing the dimensions of hunger ("not at all hungry-very hungry" and fullness ("not at all full-very full") [see appendix A4].

Following completion of odour evaluation, Group 1 remained in the laboratory under experimental supervision while Group 2 received a prescribed meal before both groups again participated in a second EEG session. One methodological alteration in the present experiment was that subjects completed the psychometric odour and hunger/fullness rating exercise immediately after the first testing session and immediately before the second testing session. The length of time between ingestion and rating at the second session therefore would be no more than five minutes. It was

believed that this would potentiate any olfactory alliesthesia since it is possible that the time latency between eating and rating in experiments two and three may have influenced the results. The second EEG session was run as in the first session. Following completion of this second session, subjects were debriefed, paid and received a free brain map.

### **7.5. *The Lunch.***

The lunch differed in content slightly from that of experiments one and two. Subjects in the Lunch groups still received a bowl of vegetable soup, baked beans with potato, and carbonated water (in measurements as described earlier) and also received a chocolate dessert mousse. Thus the meal composition mirrored that of a complete meal with starter, main meal and dessert. Cooked food was prepared as in experiments one and two.

### **7.6. *EEG recording.***

EEG was collected as described in experiment two except that the odour exposure period was extended to 30 epochs (1 min. 16 secs.) to allow for adequate artifact-free epoch samples, with no pre- or post-odour recordings. In addition, 30 epochs of "baseline" EEG were recorded before any of the odours were presented. This condition represented the overall control. The inter-odour interval was 1 minute. No subject reported detecting an odour prior to the presentation of the following stimulus. Data were collected from 19 electrodes in all five frequencies (see Fig. 7). The nineteen electrodes selected for analysis were those selected in experiment two. Artifact procedures were followed as in the previous experiment.

LEFT

RIGHT

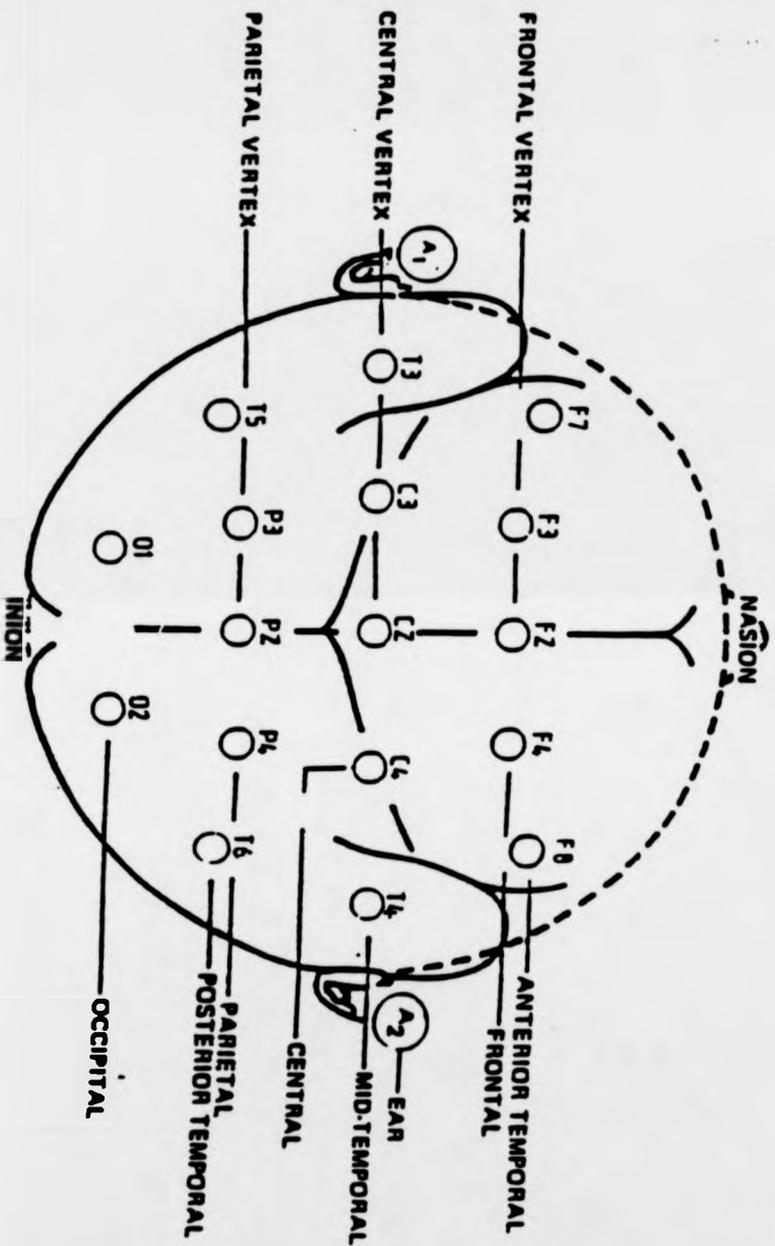


Fig. 7. Electrode array used for analysis in experiment three.

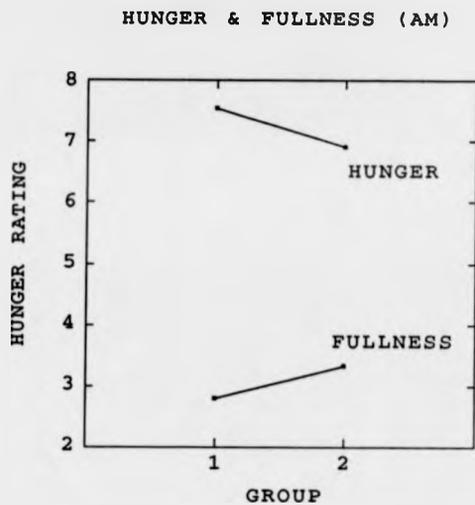
## **RESULTS**

### ***7.7. Psychometric results.***

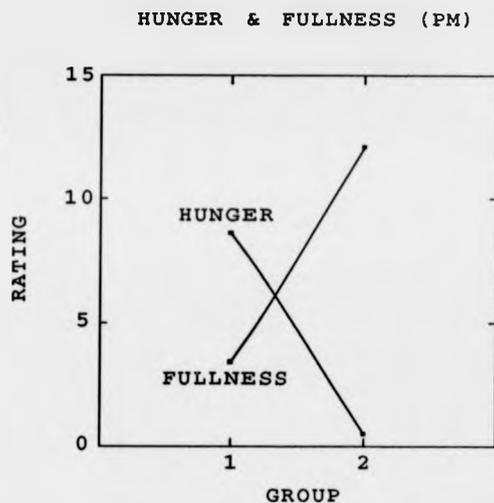
#### ***7.7.i. Hunger and fullness ratings.***

The data from the hunger and fullness scales were submitted to two, separate two-way repeated measures analyses of variance with group and time-of-day as factors. There was a significant main effect of time-of-day and a significant time-of-day x group interaction [ $F(1,12)=9.97, p=0.008$ ]. As expected the lunch group gave significantly lower hunger ratings after lunch than before (i.e. reported experiencing less hunger) as well as giving lower ratings in the afternoon than did the control group (i.e. the lunch group reported less hunger than the controls) [Tukey's HSD,  $df=12, p<0.0001$  and  $df=12, p<0.0005$  respectively]. There was no significant difference between the a.m. and p.m. ratings of the controls or between the a.m. ratings of the lunch and control group.

Fullness ratings appeared to mirror those for hunger. Again, there was a significant interaction between time-of-day and group [ $F(1,12)=38.96, p<0.00005$ ]. This interaction paralleled that for hunger with the lunch group reporting greater fullness after lunch than before ( $df=12, p<0.0005$ ) and the lunch group also reporting greater fullness in the afternoon than the controls ( $df=19, p=0.002$ ). As expected, there was a significant correlation between hunger and fullness ratings in the afternoon ( $r=-0.96, p<0.00001$ ) but not in the morning ( $r=-0.29, p=1.00$ ) which presumably reflects the variability of these two dimensions pre-prandially. The relationship between ingestion and hunger and fullness ratings can be seen in **Figs. 7. i. a & b.**



*Fig. 7.i.a. illustrates the a.m. ratings of both groups for hunger and fullness (0=hungry/not full; 12.5=not hungry/very full). There appears to be little group difference between the rating responses on either dimension. Control group=Group 1; Lunch group=Group 2.*



*Fig. 7. i.b. illustrates the p.m. ratings for hunger and fullness for controls (Group 1) and Lunch group (Group 2). 0=hungry/not full; 12.5=not hungry/very full.*

**7.7.ii. Does the odour induce hunger?**

To determine the relative ability of odours to induce hunger, pre-and post-prandially, this dimension was submitted to a three-way ANOVA. A significant main effect of odour [ $F(4,44)=7.38, p=0.002$ ] was found for this dimension. Post-hoc analysis showed that the pairwise effects were limited to hot water-beans and beans-meat comparisons where the beans made the subjects significantly more hungry relative to hot water and the rotting meat. **Table 7a.** shows the odours ranked along this dimension. The odour of baked beans appeared to be a stimulus which was able to generate considerable feelings of hunger in hungry subjects. The lack of palatability of

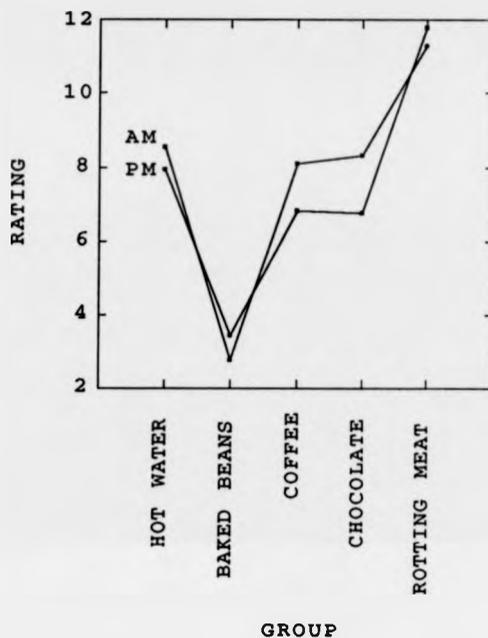
hot water and rotting meat suggests that the odour of a pleasant, stereotypical foodstuff can induce hunger to a greater extent than neutral or unpleasant food odours.

**Table 7a.** Odours rated for their ability to induce hunger (control vs lunch group data). 0= Makes me very hungry; 12.5=Does not make me at all hungry. There were 8 subjects in each group.

ODOUR	GROUP 1 (No-Lunch)	GROUP 2 (Lunch)
HOT WATER (AM)	8.51 (3.4)	10.83 (2.5)
(PM)	7.9 (3.3)	10.49 (2.7)
BAKED BEANS (AM)	2.75 (3.01)	6.16 (4.1)
(PM)	3.44 (3.3)	9.8 (2.8)
COFFEE (AM)	8.1 (3.2)	7.64 (4.7)
(PM)	6.83 (2.1)	11.09 (3.0)
CHOCOLATE (AM)	8.3 (3.8)	6.81 (4.8)
(PM)	6.77 (3.9)	10.2 (3.2)
ROTTING MEAT (AM)	11.3 (2.5)	9.83 (4.2)
(PM)	11.8 (1.06)	10.73 (4.2)

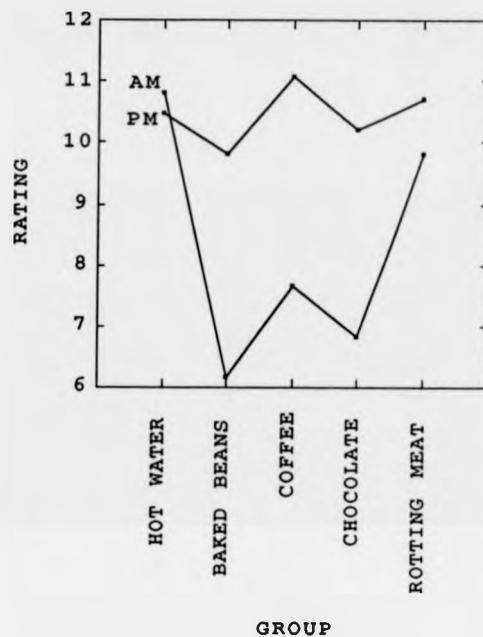
A significant time-of-day x group interaction [ $F(1,11)=11.97, p=0.005$ ] was also obtained. Odours induced greater hunger ratings in the control group than the lunch group ( $t=2.91, df(12), p=0.013$ ), a finding which attests to the satiating effects of the ingested meal, as illustrated by **Figs. 7.ii. a-c.**

## HUNGRY DIMENSION FOR CONTROLS (AM vs PM)



*Fig. 7.ii.a illustrates differences between the control group's a.m. and p.m. response to the question, "does this odour make you hungry?" (0=makes me hungry; 12.5=does not make me hungry). The group's ratings do not appear to show any difference between sessions.*

## HUNGRY DIMENSION FOR LUNCH GP (AM vs PM)



*Fig. 7.ii.b. illustrates differences between the lunch group's a.m. and p.m. responses to the question "does this odour make you hungry?" (0=does make me hungry; 12.5=does not make me hungry). there is a marked difference between the a.m. and p.m. responses to beans, coffee and chocolate.*

## HUNGRY DIMENSION PM (CONTROLS vs LUNCH)

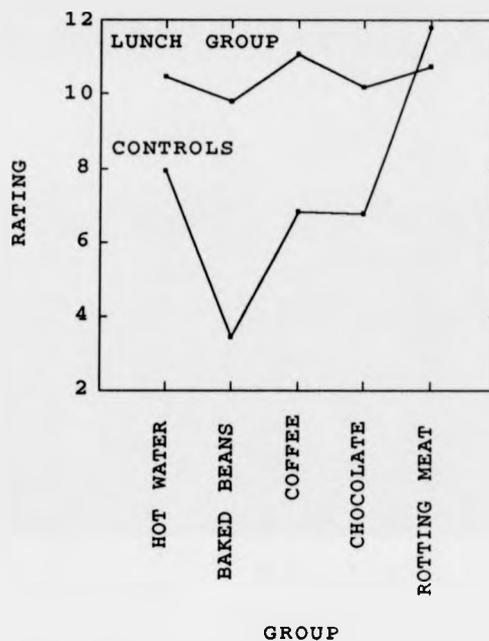


Fig.7.ii. c. illustrates differences between the p.m. responses of the control and lunch groups to the question "does this odour make you hungry?" (0=does make me hungry; 12.5=does not make me hungry).

7.7.iii. Odour identification.

To investigate the possibility of differences in the identifiability of odours, a Cochran's test for repeated measures design was used as in experiments one and two. A sign test revealed significant differences between chocolate and hot water and rotting meat. Chocolate was identified better than either of these odours ( $p=0.031$  and  $0.004$  respectively) both of which tended to generate incorrect but plausible descriptors (eg.,

cheese for rotting meat; tea for hot water). There were trends towards significance for the beans-meat and coffee-meat comparisons but not significantly so. The trends nonetheless indicated the relative unidentifiability of meat compared with the other odours. The relationship between identification and the odour's familiarity is presented in **Table 7b**.

**Table 7b.** Odours ranked according to identifiability (most to least) and familiarity (most to least). Means with standard deviations in brackets (for familiarity only).

Identification	Familiarity
Chocolate	Baked beans 1.57 (1.02)
Baked beans	Coffee 2.45 (2.71)
Coffee	Chocolate 2.85 (1.93)
Hot water	Hot water 5.42 (3.16)
Rotting meat	Rotting meat 6.9 (3.35)

(0= familiar; 12.5=not at all familiar)

**7.7.iv Psychometric ratings: pleasantness, familiarity, strength, alertness, happiness and hungriness.**

The data from the psychometric ratings were submitted to separate three-way repeated measures analyses of variance with group, time-of-day and odour as factors. The results for the pleasantness, strength, familiarity, alertness and happiness dimensions are summarised in **Table 7c**.

**Table 7c.** A summary the psychometric ratings of the hot water, baked beans, coffee, chocolate and the rotting meal odours. Means are given with standard deviations in brackets. Ratings are ranked from most to least (pleasant, strong, familiar, etc.)

	Pleasantness	Strength	Familiarity	Alertness	Happiness-Inducement
BB	3.52 (3.08)	RM 11.7 (1.0)	BB 1.57 (1.01)	RM 4.31 (2.79)	BB 4.99 (3.32)
COF.	3.99 (2.91)	BB 10.7 (1.98)	COF. 2.45 (2.71)	COF. 5.72 (2.84)	CH. 5.17 (2.85)
CH.	4.16 (3.31)	COF. 9.64 (3.39)	CH. 2.85 (1.93)	BB 7.79 (1.64)	CO. 5.35 (2.99)
HW	6.31 (2.05)	CH. 9.23 (2.73)	HW 5.42 (3.16)	CH. 7.86 (2.34)	HW 6.68 (1.8)
RM	11.4 (1.95)	HW 3.06 (1.81)	RM 6.9 (3.35)	HW. 8.92 (2.63)	RM 11.02 (2.79)

**KEY:**

BB=baked beans; COF.=coffee; CH.=chocolate; HW=hot water; RM=rotting meal.

*(a) Did the ingestion of lunch affect any psychometric rating?*

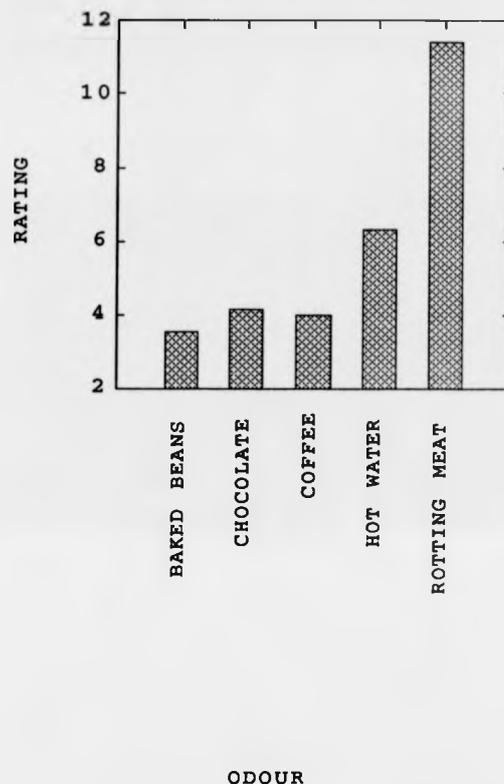
As in experiments one and two, there was no main effect of group nor any group x time of day x odour interaction for pleasantness, familiarity, strength, alertness or happiness.

*(b) Did the odours differ along any of the dimensions?*

*(b) i. Pleasantness.*

As predicted, there was a significant main effect of odour on psychometric ratings of pleasantness [ $F(4,48)=24.17, p<0.001$ ]. Post-hoc tests revealed that the differences between odours centred on the rotting meat which was rated as less pleasant than hot water ( $t=6.82, df(13), p<0.001$ ), baked beans ( $t=4.8, df(13), p<0.001$ ), coffee ( $t=8.65, df(13), p<0.001$ ) or chocolate ( $t=7.05, df(13), p<0.001$ ). **Fig. 7.iii.** illustrates these differences more clearly.

Graph illustrating differences in pleasantness between odours

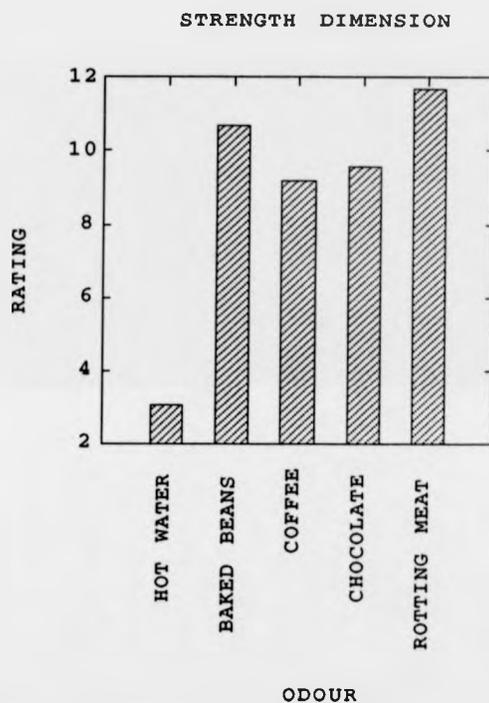


*Fig. 7.iii. represents all odours rated for pleasantness (0=pleasant; 12.5=unpleasant).*

*(b) ii. Strength.*

There was a significant main effect of odour on strength ratings [ $F(4,44)=27.31$ ,  $p<0.00001$ ] as seen in **Fig. 7.iv**. Post-hoc tests showed that the effect was, as expected, largely the result of hot water/other odour pairwise comparisons. This odour was rated weaker than baked beans ( $t=7.57$ ,  $df(12)$ ,  $p<0.001$ ), coffee ( $t=5.44$ ,

df (12),  $p < 0.001$ ), chocolate ( $t = 5.46$ , df (12),  $p < 0.001$ ) or rotting meat ( $t = 14.82$ , df (12),  $p < 0.001$ ). There was also a significant difference between chocolate and the rotting meat where chocolate was rated weaker than the meat ( $t = 3.48$ , df 912),  $p = 0.004$ ).

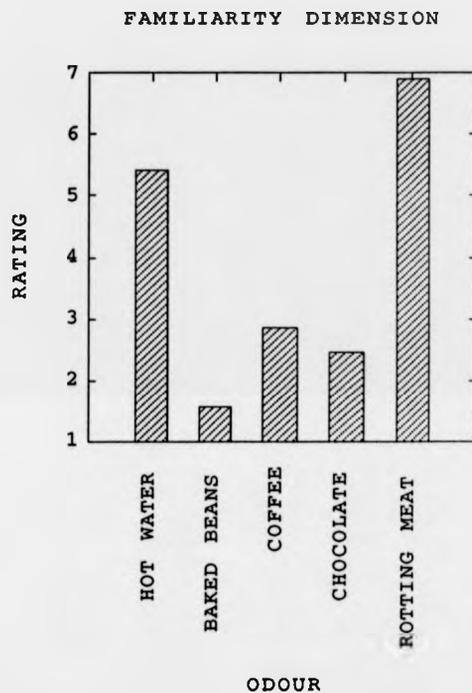


*Fig. 7.iv illustrates differences between the odours along the strength dimension (0=weak, 12.5=strong).*

**(b) iii. Familiarity.**

A significant main effect of odour was also obtained for familiarity [ $F(4,44) = 11.98$ ,  $p < 0.0001$ ]. Post-hoc tests showed that this effect was largely confined to the meat odour which was rated as significantly less familiar than baked beans ( $t = 6.81$ , df (13),  $p < 0.0001$ ), coffee ( $t = 4.31$ , df (13),  $p = 0.001$ ) or chocolate ( $t = 3.89$ , df (13),  $p = 0.002$ ).

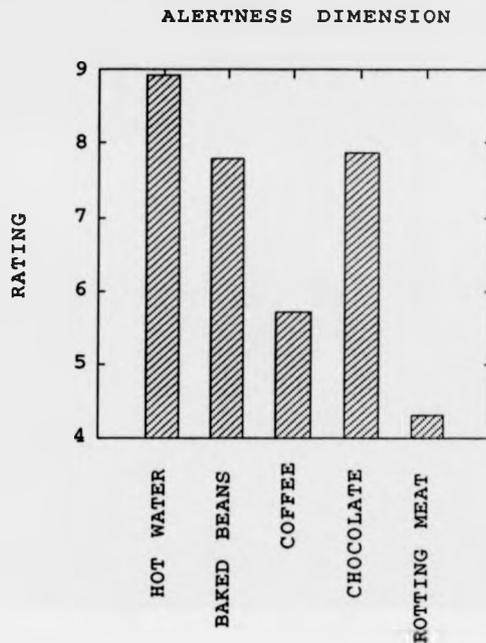
In view of the relative infrequency of contact with the malodour, this finding was not altogether surprising. There was also a significant difference between rating for hot water and baked beans with the beans being rated as more familiar than the hot water ( $t=4.81$ ,  $df(12)$ ,  $p<0.001$ ). These differences can be seen in Fig. 7.v.



*Fig. 7.v. illustrates differences between odours along the familiarity dimension (0=familiar; 12.5=unfamiliar).*

*(b) iv. Alertness.*

There was a significant main effect of odour obtained for the alertness dimension [ $F(4,44)=9.82, p<0.0005$ ] which is illustrated in **Fig. 7. vi**. Post-hoc analysis showed that this effect was due to the rotting meat which was rated as more alerting than hot water ( $t=4.38, df(12), p=0.001$ ), baked beans ( $t=4.05, df(13), p=0.001$ ) or chocolate ( $t=4.12, df(13), p=0.001$ ). In view of the nature of this stimulus it is plausible that this odour should be the one which subjects find the most alerting and attests to the use of malodour as a caveat.

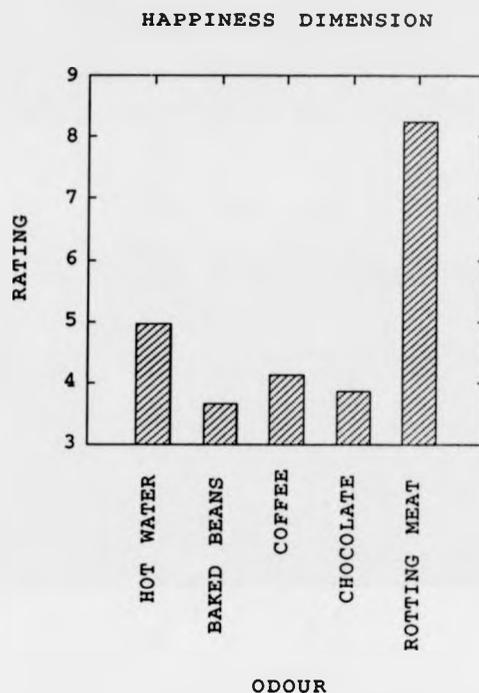


ODOUR

*Fig. 7.vi. illustrates differences between odours along the alerting-relaxing dimension (0=alerting; 12.5=relaxing).*

*(b) v. Does the odour induce happiness?*

This dimension showed a significant main effect of odour [ $F(4,44)=16.43$ ,  $p<0.00005$ ] as seen in Fig. 7. vii. Post-hoc analysis revealed that this effect was produced by the rotting meat which did not make subjects as happy as did the baked beans ( $t=5.06$ ,  $df(13)$ ,  $p<0.001$ ), hot water ( $t=7.26$ ,  $df(12)$ ,  $p<0.001$ ), coffee ( $t=7.39$ ,  $df(13)$ ,  $p<0.001$ ) or chocolate ( $t=6.45$ ,  $df(13)$ ,  $p<0.001$ ).



*Fig. 7.vii. illustrates differences between odours for the "does the odour make you happy" dimension? (0=does not; 12.5=does). Rotting meat, as expected, performs remarkably poorly on this dimension.*

**7.7.v. Would subjects eat the food emitting the odours used?**

To further determine the repugnant nature of the rotting meat and the palatability of the other foods, subjects were asked whether they would eat any food emitting the odour they had smelled. Since this repeated measures design employs a Yes/No response, Cochran's test was used to analyse the results. A sign test showed that there were significant differences between odours, largely the result of the influence of rotting

meat. Food emitting this odour would not be eaten by the subjects in comparison to baked beans ( $p=0.002$ ), coffee ( $p=0.004$ ) or chocolate ( $p=0.002$ ).

### *7.8. EEG results.*

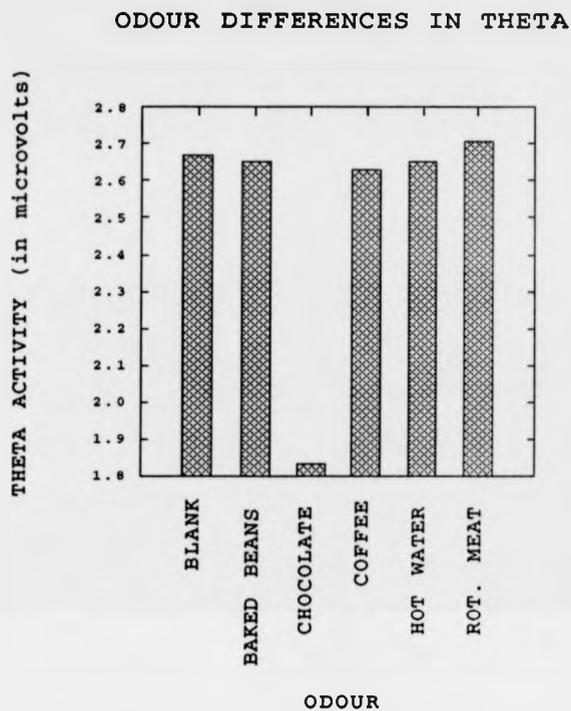
Data from the EEG experiment were log transformed to account for possible skewing and were submitted to a three-way repeated measures analysis of variance with group, time-of-day and odour as factors. For each of the main factors, all EEG frequencies were analysed.

#### *7.8.i. Effects of odour.*

A main effect of odour was obtained for theta (FZ: [F (5,20)=90.08,  $p<0.001$ ]; T5: [F (5,20)=4.39,  $p=0.038$ ]), alpha (O1: [F (5,20)=4.01,  $p=0.05$ ]; O2: [F (5,20)=4.45,  $p=0.049$ ]) and beta 1 (C4: [F (5,20)=5.66,  $p=0.013$ ]). There were no main effects of odour for delta or beta 2.

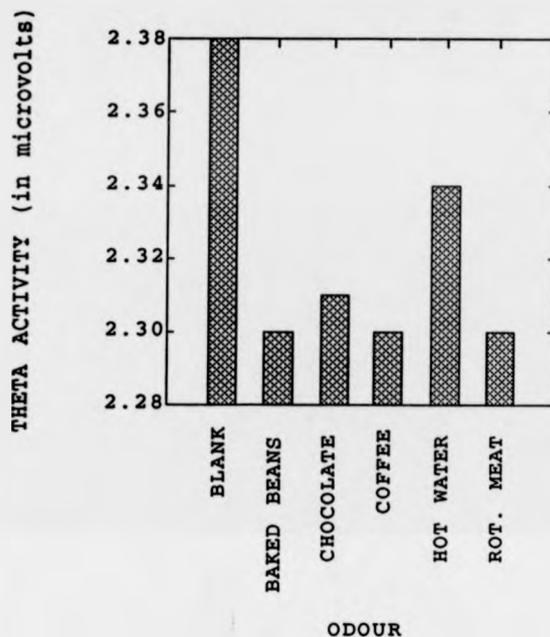
#### *(a) Theta.*

Post-hoc analysis showed that the main effects of odour were produced at FZ by the chocolate odour which generated less relative theta activity than all other odours (no-odour control- $t=9.84$ ,  $df(5)$ ,  $p<0.001$ ; baked beans-  $t=13.94$ ,  $df(5)$ ,  $p<0.001$ ; coffee- $t=9.99$ ,  $df(5)$ ,  $p<0.001$ ; hot water-  $t=11.88$ ,  $df(5)$ ,  $p<0.001$ ; rotting meat-  $t=16.88$ ,  $df(5)$ ,  $p<0.001$ ). At T5, the odour of rotting meat generated significantly less theta than did the no-odour control ( $t=5.18$ ,  $df(6)$ ,  $p=0.002$ ). Figs 7.viii. and 7.ix. illustrate this relationship between the odours.



*Fig. 7. viii. illustrates the differences in theta activity generated by the odours at electrode site FZ. As is clear from the graph, chocolate appears to produce a markedly different response in this frequency to the other odours. EEG data are for theta (log).*

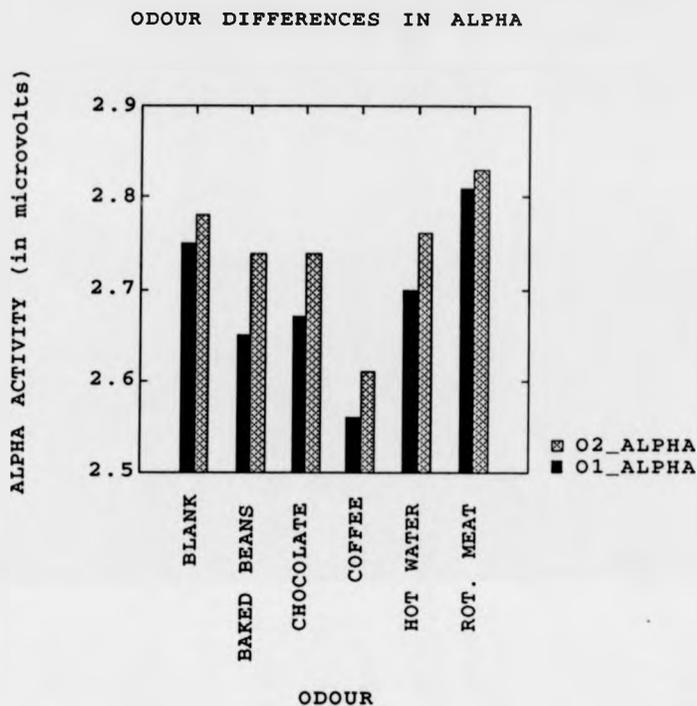
## ODOUR DIFFERENCES IN THETA



*Fig.7.ix. illustrates differences between odours in the theta frequency at the T5 electrode site. There appear to be marked differences between the blank (control) and other odours, although only comparisons between blank and the odour of rotting meat reached significance. EEG data are for theta (log).*

*(b) Alpha.*

In both cases where significant results were obtained for alpha, more alpha activity was present during exposure to chocolate than to meat (O1:  $t=5.12$ ,  $df(5)$ ,  $p=0.004$ ; O2:  $t=4.25$ ,  $df(5)$ ,  $p=0.008$ ). The relationship between these odours can be seen more graphically in Fig. 7. x.



*Fig. 7.x. illustrates the EEG differences between odours for the occipital electrodes O1 and O2. Data are for alpha (log).*

*(c) Beta 1.*

A similar relationship between rotting meat and chocolate results was found in beta 1 where chocolate was associated with significantly more activity in this frequency than was the rotting meat odour ( $t=6.02$ ,  $df(5)$ ,  $p=0.002$ ). There were no other effects of odour.

### *7.8.ii. Effects of time-of-day.*

There was a significant main effect of time-of-day for theta (F7: [F (1,4)=26.68,  $p=0.007$ ]; T3: [F(1,4)=6.89,  $p=0.05$ ]; FZ: [F(1,4)=38.58,  $p=0.003$ ]), alpha (PZ: [F(1,4)=7.15,  $p=0.05$ ]), beta 1 (T3: [F (1,4)=20.41,  $p=0.011$ ]) and beta 2 (T3: [F (1,4)=8.23,  $p=0.046$ ]). From these initial results, it would appear that the left temporal region appears especially sensitive to time-of-day effects in these bands.

#### *(a) Theta.*

For both left frontal and left anterior sites, theta activity was greater in the afternoon than in the morning (F7:  $t=5.05$ ,  $df(5)$ ,  $p=0.004$ ; T3:  $t=2.87$ ,  $df(5)$ ,  $p=0.035$ ). For frontal-central sites, however, there was significantly less theta in the afternoon than in the morning (FZ:  $t=6.94$ ,  $df(5)$ ,  $p=0.001$ ).

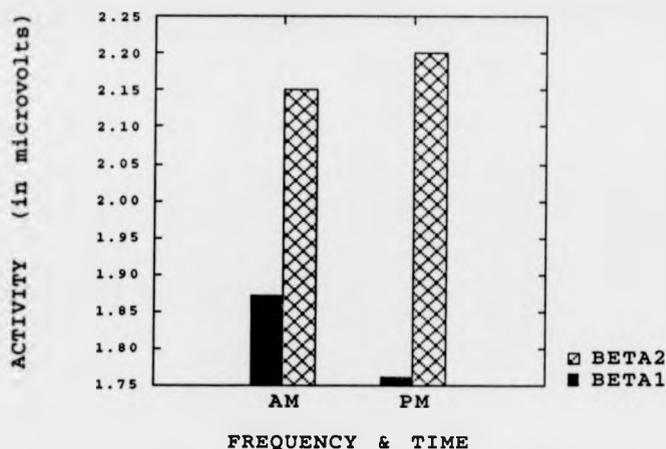
#### *(b) Alpha.*

At the central-parietal site, greater alpha was generated during the afternoon than during the morning (PZ:  $t=2.99$ ,  $df(5)$ ,  $p=0.03$ ). There were no other time-of-day effects for alpha.

#### *(c) Beta 1 and 2.*

At the left posterior site, beta 1 activity was greater in the morning than in the afternoon ( $t=4.97$ ,  $df(5)$ ,  $p=0.004$ ). Conversely, beta 2 activity was greater in the afternoon than the morning ( $t=3.06$ ,  $df(5)$ ,  $p=0.028$ ). The relationship between these two electrodes can be seen in **Fig. 7. xi**. There were no other effects of time-of-day on the beta wavebands.

## AM/PM DIFFERENCES IN BETA 1 &amp; 2



*Fig. 7. xi. illustrates time-of-day differences for the beta 1 and beta 2 bands for the electrode, T3. An inverse relationship appears to exist between the two frequencies: Activity increased the afternoon for beta 2 whereas activity decreased for beta 1. Data are for beta 1 & 2 (log).*

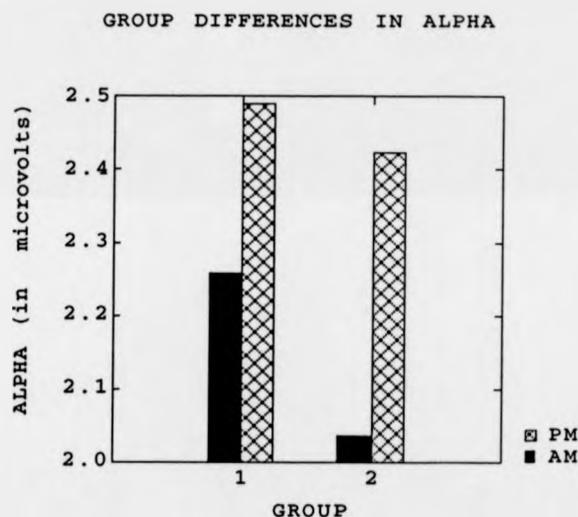
**7.8.iii. Did odour and time-of-day interact?**

There were odour x time-of-day interactions for alpha (FZ: [F (5,20)=112.92,  $p<0.001$ ]) and beta 2 (CZ: [F (5,20)=4.55,  $p=0.041$ ]), both at central locations.

For alpha, less activity was generated during exposure to chocolate in the afternoon than in the morning ( $t=11.77$ ,  $df(5)$ ,  $p<0.001$ ). For beta 2, the interaction was due to hot water which was associated with greater beta 2 power in the afternoon than the morning ( $t=3.47$ ,  $df(5)$ ,  $p=0.018$ ). There were no other significant odour x time-of-day interactions.

*7.8.iv. Did odour, group and time-of-day interact?*

There was a significant three-way interaction for the alpha waveband at the right anterior region (F8: [F (5,20)=3.91, p=0.055]). Post-hoc analysis revealed that this interaction was due to the EEG activity of the lunch group, as reflected in Fig. 7.xii. This group showed greater alpha activity post-prandially than pre-prandially ( $t=5.30$ ,  $df(2)$ ,  $p=0.034$ ).



*Fig. 7.xii. illustrates group differences in alpha activity between the two testing sessions (1=control group; 2=lunch group) for the electrode F8. As is clearly seen, there is a significant difference within the lunch group with greater alpha generated during the second session. EEG data are for alpha (log).*

### 7.8. v. *EEG asymmetry and pleasantness ratings.*

#### (a) *Asymmetry between odours.*

As in experiment two, asymmetry indices were calculated for four topographical regions (frontal, parietal, anterior-temporal and central) for alpha and theta frequencies. These indices were calculated for the odours which subjects rated most pleasant and least pleasant and compared with a neutral control. From the psychometric data, it is apparent that baked beans gave the highest pleasantness rating (3.52) and rotting meat the highest unpleasantness rating (11.4). This was confirmed by ANOVA (see above). The blank, no-odour condition was used as neutral control. To examine further the possible effects of lunch consumption on EEG response during olfactory stimulation, the p.m. data for each group were analysed separately from the a.m. data.

No main effect of odour was found for the alpha waveband. However, a significant main effect of odour was obtained for theta [ $F(2,16)=4.54$ ,  $p=0.032$ ]. Post-hoc analysis showed that this effect was due to the comparison between baked bean and rotting meat odours ( $t=3.66$ ,  $df(8)$ ,  $p=0.006$ ). More left-sided frontal activity was apparent for the baked beans (index: 10.04) relative to the rotting meat (10.005).

An odour x group effect interaction was obtained in the theta waveband [ $F(2,20)=5.89$ ,  $p=0.011$ ]. This interaction was largely due to the control group which generated greater right-sided parietal activity to the odour of baked beans when compared with the lunch group (Tukey's,  $df(16)$ ,  $p=0.031$ ) (Controls' index: 9.87; lunch group: 9.99). A significant difference was also found between the lunch group's asymmetry for the blank condition (index: 9.91) and baked beans (9.99) (Tukey's,  $df(20)$ ,  $p=0.027$ ). For this group, greater right-sided parietal activity was found for the blank condition with the baked beans approaching symmetry.

*(b) Were there any differences in asymmetry location for each odour?*

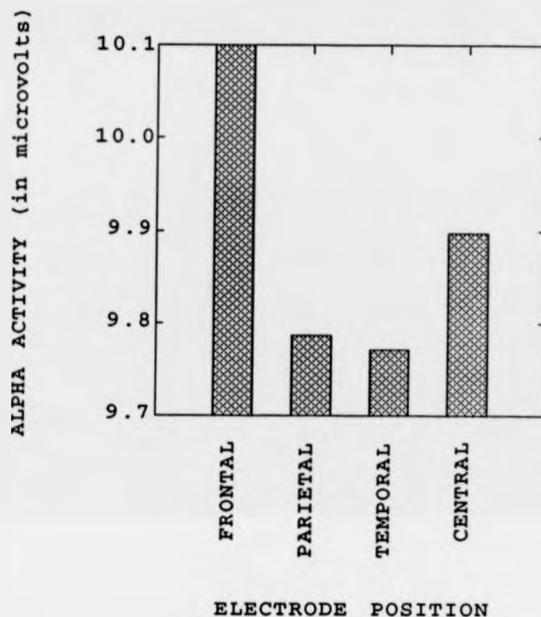
To determine whether there were differences in asymmetry for individual odours at different locations, the data were submitted to a univariate ANOVA with position as factor. As in the above analysis, the p.m. data were considered separately.

There was a significant main effect of position in alpha for the baked bean odour [ $F(3,30)=3.1$ ,  $p=0.056$ ], as reflected in **Fig. 7. xiii.** (overleaf). Post-hoc analysis showed that this effect was due to a difference in asymmetry between frontal and anterior-temporal sites ( $t=2.75$ ,  $df(10)$ ,  $p=0.02$ ). Greater left-sided activity was found at frontal (index: 10.10) sites than at temporal locations (9.77).

A significant group x position interaction was obtained for the p.m. data in the alpha waveband [ $F(3,33)=2.98$ ,  $p=0.051$ ]. Here, significantly greater asymmetry was evident for the control group at anterior-temporal sites during exposure to rotting meat ( $t=2.52$ ,  $df(11)$ ,  $p=0.028$ ). This group showed greater right-sided temporal activity to rotting meat (Controls' index: 9.72; lunch group: 9.97).

A main effect of group was obtained for the rotting meat in theta [ $F(1,11)=6.031$ ,  $p=0.032$ ]. This effect was due to greater relative overall right hemisphere activity in the control group compared with the lunch group (controls' index=9.88; lunch group=10). As can be seen, the lunch group's index reflects perfect theta symmetry.

## POSITION DIFFERENCES IN ASYMMETRY



*Fig. 7. xiii. illustrates differences in the distribution of alpha asymmetry for the baked bean odour. It is evident that frontal sites generated greater left-sided activity than any of the other sites. Data are for alpha (log) based on the asymmetry index  $\text{Log Left} - \text{Log Right} + 10$ .*

**7.8.vi. EEG asymmetry and alertness ratings.**

Data from those odours rated as most alerting, calming and neutral were taken to form an asymmetry index for the four electrode-pair locations. These odours were rotting

meat (4.31) and hot water (8.92), respectively. Alpha and theta were analysed. The p.m. data were considered separately.

*(a) Differences between odours.*

There was no effect of odour on position asymmetry for alpha but a significant effect was obtained for theta [ $F(2,16)=3.61$ ,  $p=0.055$ ] at central areas. Post-hoc analysis showed that the odour of rotting meat (index: 9.97) was associated with greater right-sided activity than was the hot water (10.03) (Tukey's,  $df(16)$ ,  $p=0.028$ ).

A main effect of group was obtained in p.m. alpha at anterior-temporal regions [ $F(1,11)=5$ ,  $p=0.047$ ]. Here, there was a significant difference between the control and lunch group for the rotting meat odour ( $t=2.52$ ,  $df(11)$ ,  $p=0.028$ ). Both groups showed more right-sided activity but the control group showed greater right-sided activity compared to the lunch group (controls' index=9.73; lunch group=9.96).

*(b) Differences in asymmetry by position.*

There was a main effect of electrode position in p.m. alpha for the hot water stimulus [ $F(3,33)=3.7$ ,  $p=0.025$ ]. The control group showed greater right-sided temporal activity to this odour than did the lunch group ( $df(42)$ ,  $p<0.001$ ; controls' index=9.66; lunch group=9.96). There was also a group x position interaction for hot water in alpha [ $F(3,33)=3.89$ ,  $p=0.021$ ]. The interaction was due to effects within the control group and to differences between the lunch and control group at central areas. The control group showed greater right-sided activity at temporal areas than at frontal ( $df(33)$ ,  $p<0.001$ ), parietal ( $df(33)$ ,  $p<0.001$ ) and central ( $df(33)$ ,  $p<0.001$ ) areas. The control group also showed greater right-sided activity at central areas (index: 9.9) than did the lunch group (9.96) ( $df(33)$ ,  $p<0.001$ ). There were no other main effects of position and no other interactions.

## 7.9. Discussion.

### 7.9.i. Pre- and post-prandial hedonic response to odour.

As in experiments one and two, and contrary to Ducleaux *et al* (1973) and Cabanac (1979), no effect of lunch was found on post-prandial ratings of the pleasantness of food odour. This finding was obtained even though two of the odours rated were emitted by the ingested food. This evidence, coupled with that of the previous experiments, lends strong support to the hypothesis that olfactory-specific satiety and negative olfactory alliesthesia are highly irregular phenomena which are not easily replicable.

The factor of time has been cited as a possible explanation for the variability of sensory specific satiety (SSS) and negative alliesthesia (Rolls *et al*, 1986). Normally, the greater the propinquity between ingestion and rating, the stronger the SSS and negative alliesthesia. A greater latency between eating and rating may produce weaker alliesthesia or no alliesthesia at all. In the current experiment, all subjects rated the food odours immediately after eating their lunch (if they comprised the lunch group) or immediately after the thirty minute inter-session interval (for the control subjects). Thus, although the duration between eating and rating was kept to a minimum, olfactory alliesthesia continued to be unobserved.

A possible objection raised in **Chapter 6** was that hunger was not responsible for the alliesthesia *per se* but the fullness experienced after a meal (i.e. satiety proper). Yet, in the present experiment, those subjects who had eaten lunch reported being significantly fuller after lunch than before and significantly fuller than controls. This effect was not relative since the post-prandial rating was high (12). Thus the fullness factor appeared to have no effect on the odour ratings.

Although fed subjects rated the the odours of chocolate, coffee and baked bean as less hunger-inducing than did unfed controls, there was no concomitant decrease in odour pleasantness. It appears, therefore, that exposure to food odour after ingesting a lunchtime meal reduces the degree of hunger generated not only by the odours of the foods eaten (baked beans, chocolate) but also by food not eaten (coffee). Surprisingly, the rating given for the hunger-inducing ability of coffee was also significantly lower in the fed group than in controls. One might have expected no change in the rating for coffee or possibly an increase in its desirability following the ingestion of a meal. One possible explanation for this finding may be due to the way in which the question was worded. The subject was asked : "Does this odour [coffee] make you hungry?" It is possible that this question was misinterpreted as "Does this odour make you generally hungry?" and not "Does this odour make you hungry for coffee?" The subjects' satiated state may thus have dictated their response to this question. The ratings for hot water and rotting meat, as expected, showed no significant difference in rating before and after lunch, between or within subjects.

On the basis of these findings, it is possible to construct a modified version of the "strong" negative alliesthesia hypothesis which would state that the pleasantness of food odour will decrease with satiety when compared with pre-prandial ratings. The modified version would argue that it is not the hedonic component of the odour which changes but the odour's effect on hunger for food. Subjects did not like the food odours less after eating their lunch but these odours did not induce hunger to as significant a degree as it did pre-lunch. This hypothesis and a general consideration of the psychometric results reported here are discussed in **Chapter 8**.

*7.9.ii. EEG results: Effects of odour.*

As in experiment two, marked differences were found between odours in the theta frequency. At central locations, the odour of chocolate was associated with significantly less theta activity than any other odour or blank baseline. Further theta differences were found in the left temporal region with the odour of rotting meat generating less theta compared with the blank condition. In experiment two, the odour of chocolate was rated as highly relaxing and soothing. In the present experiment, however, hot water was rated as the most relaxing of the odours. Rotting meat, not surprisingly, was rated as significantly different from all other odours for the pleasantness, alertness and happiness dimensions with all other odours rated favourably by comparison. Chocolate, however, was rated fairly highly on the pleasantness and relaxation dimensions which suggests that there may be some psychophysical property of this odour (probably those mentioned) which affects the theta frequency. In view of the hypothesis proposed in **Chapter 6** that less theta=increased relaxation/decreased tension, this finding provides further evidence to support such a hypothesis. No significant differences were found between hot water and chocolate on the relaxation and alertness dimensions which suggests that there is a property of chocolate odour which is capable of generating effects on the EEG, particularly effects which are related to the odour's association with increased relaxation. It is possible that the subjects were responding more to the tactile sensation produced by the hot water and not its odour (for the simple reason that the water had no odour). The odour of chocolate was also associated with differences in the alpha frequency showing greater bilateral occipital activity to this odour than for rotting meat. The significance of the alpha frequency to odour processing is unclear. As noted in **section 4.10., Chapter 4**, odour rarely exerts effects in this frequency. The postulated generating site for alpha is the occipital region although even this is not completely certain (Andersen & Andersson, 1968; Niedermeyer, 1987). That the

odour-effect should have been generated bilaterally in this area and to two odours who's hedonic psychometric ratings differed markedly, suggests that this frequency in this region may be particularly susceptible to these kinds of stimuli. The increased activity to the odour of rotting meat suggests that the affected area of the scalp may be highly influenced by a highly attention-reducing odour such as rotting meat. If a stimulus is classed as alerting (which it was in this experiment) or distracting (which wasn't examined), if alpha is considered a reliable index of attention (Ray & Cole, 1985), and if the generating source of alpha is in the occipital region, then the result obtained here is not unexpected. Furthermore, the odour of rotting meat was also associated with less theta activity compared with the no-odour control. This finding would appear to support an attentional hypothesis of theta function as suggested in section 6.10.ii. of Chapter 6. This hypothesis and the evidence for it will be reviewed in greater detail in the following chapter. It is possible that it is this attentional feature of olfactory perception which may account for the reliable changes in EEG theta.

#### *7.9.iii. Time-of-day effects.*

Time-of-day differences were observed in several wavebands with greater alpha and theta (at left frontal and anterior regions) present in the second session than the first. This change in alpha was also reported in experiment two. An inverse relationship between beta 1 and 2 was observed at left temporal sites with greater beta 1 in the first session than in the afternoon and greater beta 2 in the afternoon than in the morning. It is interesting to note that all time-of-day effects were restricted to either midline or left hemisphere electrodes. Very little is known concerning time-of-day differences in the waking EEG (Niedermyer, 1987). Many studies claim to have found Basic-Rest-Activity-Cycles (BRAC, Aserinsky & Kleitman, 1953) in normal EEG (e.g., Manseau & Broughton, 1984) or have used much longer recording periods to that in the current

experiment (e.g., Gundel & Hilbig, 1983; Tsuji & Kobayashi, 1988) or measure electrophysiological fluctuations before, during and after sleep (Rechtschaffen & Kales, 1968; Torsvall & Akerstedt, 1987). It is possible that waveband changes reported here are related to time-of-day but, as noted in **Chapter 6 (section 6.10.iii.)**, these changes may be due to familiarity with the testing procedure and recording protocol.

**7.9.iv. EEG asymmetry and odour pleasantness.**

An intra-hemispheric difference in alpha activation was observed for the most pleasant odour, that of baked beans, which appears to reflect the type of activation found by Davidson and his colleagues. Significantly greater left hemisphere alpha activation was found for this odour at frontal sites than at temporal sites. As noted above, previous investigations using film clips have shown increases in alpha at similar regions as a result of exposure to a pleasant film. The alpha asymmetry which reflects this affective response would thus appear not to be modality specific. The different pattern of EEG activity evidenced in studies using visual stimuli is also found with olfactory stimuli. It may be worthwhile to consider whether these EEG asymmetries may also be elicited by stimuli in other sensory modalities such as audition and touch. Although the neural organization of these sensory systems differs considerably, it is reasonable to ask whether the affective response to such a stimulus would be reflected in a homogeneous region of the brain, viz., the frontal and anterior cerebral cortex, a region which may play a considerable, if not instrumental, role in mediating emotional experience (Robinson & Szetela, 1981; Sackeim, Greenberg, Weiman, Gur, Hungerbuhler & Geshwind, 1982; Robinson, Kubos, Roa & Price, 1984). Evidence from clinical studies, as reviewed briefly in **section 4.14., Chapter 4**, suggests that damage to specific regions of the brain, in particular the frontal cortex, results in severe changes in affective behaviour. The manifestation of the behaviour is dependent on whether the damage is inflicted to the left or right frontal cerebral hemisphere so that depressive

symptomatology results from left frontal damage whereas euphoria and manic behaviour can occur with right frontal damage (Gianotti, 1972; Tucker, 1981; Sackeim, Greenberg, Weiman, Gur, Hungerbuhler & Geshwind, 1982; Starkstein, Robinson & Price, 1987). Davidson (1984) has also reviewed evidence from animal studies which indicates that similar selective unilateral damage has affective consequences similar to those found in humans. This hypothesis, that frontal brain regions may be important areas of mediation for emotional experiences of differing valence, will be considered more fully in the final chapter (**Chapter 8**). The regional difference in alpha found for the most pleasant odour was not repeated for the theta frequency. Here, greater relative, left frontal theta activity was found for the odour of baked beans when compared with the odour of rotting meat. This would appear to be at odds with the hypothesis put forward in **Chapter 6** that reduced theta would accompany the perception of odour that was relaxing and tension-reducing. The odour, however, was not the most relaxing of the odours used but was still rated as fairly relaxing. In view of the pleasantness rating of the baked beans it is plausible to argue that the asymmetry reported for this odour when compared with that of rotting meat may not be related to any "anxiety"-based property of the odour, but its overall quality of pleasantness. That differences were found between the two extremes in the odour range (most pleasant and least pleasant) and in the left frontal region and that this is the region associated with different EEG patterns as a result of altering emotional valence, the hypothesis can be put forward that activity in the theta band operates in a fundamentally different, if unsystematic, way from alpha. As noted in **Chapter 6**, the psychological significance of theta has been related to changes in emotional response (Walter, 1959; Maulsby, 1971; Knott, 1976; Cohen *et al.*, 1976; Lorig & Schwartz, 1988). It is possible that this frequency may operate in a similar but different way to alpha when an individual is exposed to odour which has distinct hedonic properties. If these distinct hedonic properties are viewed as stimuli inducing approach and withdrawal behaviours, which

the stimuli used the present experiment can be, then one can argue that activity in theta reflects these properties for olfactory stimuli. Thus greater left hemisphere theta to an "approach" stimulus (the baked bean odour) contrasts with the significantly less activity generated as a result of exposure to a "withdrawal" stimulus (the odour of rotting meat). Arguably, theta is the EEG index of this olfactory dichotomy. This notion, the evidence for it, and an alternative interpretation is discussed in more detail in the next chapter.

As no post-prandial changes in the hedonic rating of the food odour emerged from the present study, hedonically-related alterations in EEG asymmetry as a result of food ingestion were not expected. However, the lunch group showed significantly greater right-sided temporal alpha activation to rotting meat than did controls, a finding which partially supports previous studies showing increased activation in this area to negative emotional stimuli (Wheeler et al, 1993). The temporal lobes, and especially the right temporal lobe, have been argued to play an integral role in the perception of affective stimuli, especially "negatively" rated stimuli since the efferent and afferent connections between these lobes and the orbital frontal cortex and their connections with the amygdala, are considerable (Nauta, 1971; Horel & Misanstone, 1974; Horel, Keating & Misanstone, 1975). Some authors have suggested a role for the temporal lobes in the identification and detection of odour on the basis that damage to these areas result in deficits in these tasks (Eskenazi, Cain, Novelly & Mattson, 1986; Jones-Gottman & Zatorre, 1988a, b). Right-sided alpha activation has also been reported with negative stimuli (Wheeler *et al*, 1993) and in depressed patients (Henriques & Davidson, 1989). In view of the unpleasant nature of the rotting meat stimulus, this regional difference in the activation of alpha is predictable. That the regional difference, however, occurred between fed and unfed groups is more intriguing. The amygdala is known to play some part in the regulation of eating (Urson, Rosvold & Vest, 1969), Rolls & Rolls

(1973) found that amygdala-lesioned rats ate novel and familiar foods indiscriminately (whereas undamaged rats initially avoided the novel foods and gradually accepted them). Weiskrantz (1956) has observed similar, indiscriminate eating behaviour as a result of amygdala lesions. The connections between the amygdala and the temporal lobes, in non-human organisms, are extensive. In the present study, the subjects' previous experience with the rotting meat odour coupled with the ingestion of a lunchtime meal suggests that the increased activation observed at the right temporal lobe area represents some "affective gate", as the amygdala is argued to be (Kelley & Stinus, 1984). In the controls, this affective gate has functioned efficiently, and the individual has adapted accordingly. In the lunch group, this gating has obviously been affected by food ingestion which renders the odour of rotting meat, if this odour is seen as inducing withdrawal-and the EEG evidence suggests that it does-even more unapproachable. Thus, arguably, the nutritional state of the subject affects the response to a withdrawal stimulus at areas known to mediate negative responses. It is important to note that the nutritional state of the subjects and the food-related hedonic rating of the odour is not relevant to this hypothesis since the right-sided temporal changes were found with the most unpleasant odour, the food whose odour emitted this smell would not be eaten.

#### *7.9.v. Alertness asymmetry.*

The pattern of activity obtained for the relaxing and alerting odours in experiment two would suggest that significant group by odour differences would occur in theta at frontal and temporal areas. In the previous experiment, greater left frontal than temporal theta activity was found in the control group during exposure to the odour rated as most relaxing, chocolate; greater relative left-hemisphere temporal theta activity during presentation of the chocolate odour was also found in controls when compared with the lunch group. In experiment three, no significant effect of the "relaxing odour"

was found in the theta frequency. This result is not altogether unexpected since the "hot water" stimulus was not originally construed as an experimental odour but as a check on the effects of vapours arising from the cooked food used as olfactory stimuli. The finding does suggest, however, that it is the perception of a particular odour which affects brain asymmetry and not simply its relaxing properties *per se*. The perception of an inhaled chemical's "good" qualities is dependent on the way in which the stimulus is found relaxing. For the chocolate odour, the smell alone might be enough to enhance the mood of the perceiver; for the hot water, however, the enhancement might, and probably does, arise from the warm sensation in the nasal cavity produced by its vapours since this stimulus is odourless. The "relaxing" nature of the hot water may, therefore, be primarily trigeminally mediated.

The effects in theta which were obtained, however, were found with the rotting meat odour which was associated with significantly greater right-sided activity at "central" locations. This odour was also associated with greater right-sided temporal activity in controls than the lunch group. The association between an unpleasant stimulus and greater right-sided *theta frequency* activity has not been reported elsewhere although increased alpha activation at frontal brain regions has been associated with the experience of disgust or dislike (Wheeler *et al.*, 1993). The finding in theta, as opposed to alpha, provides further evidence for the implication of this frequency in the response to odour, and in particular the odour's hedonic property. The significance of the relationship between this frequency and odour perception and affect is further elaborated in the following chapter. If one assumes that theta does mediate the hedonic qualities of odour to a greater extent than alpha, then the finding of increased activity in the right hemisphere lends support to previous hypotheses regarding the type of hedonic information processed by the right hemisphere. Rotting meat was selected for use in the current experiment because of its unpleasant smell and because it is a good

example of a stimulus which induces withdrawal-type behaviour (Fallon & Rozin, 1983). Again, if we assume the salience of theta in odour perception, the right-sided activity observed here appears to provide some indirect evidence for the neural substrate for withdrawal-behaviour or, at least, for the type of stimulus capable of inducing withdrawal.

The significance of the finding that controls showed significantly greater right-sided temporal activity than did the lunch group during the presentation of the rotting meat is unclear. One possible hypothesis is that the physiological and psychological alterations brought about by the ingestion of a meal in the lunch group in some way made the fed subjects less susceptible to finding the odour repugnant, although no significant difference between the two groups was found for the pleasantness rating of this odour post-prandially. However, since this odour was rated the most alerting of those used, it is arguable that its alerting properties continued to affect hungry, unsatiated subjects whilst fed subjects, experiencing fullness and perhaps a degree of comfort after eating and sitting in a comfortable armchair were not as susceptible to this feature of the odour. Although the psychometric results show no significant difference between the lunch and control groups' alertness ratings for this odour, this finding may perhaps indicate that the psychometric measure was not sensitive to subtle shifts in the subject's perception and experience. The second psychometric rating exercise was undertaken in comfortable, but not overly comfortable, conditions whereas the subsequent second EEG testing session was undertaken in a dark room with subjects wearing a blindfold and headphones as they sat in a comfortable armchair. The context of the two "responses" may thus have led to the absence of a significant group-difference for the alertness dimension. This, however, is only a tentative suggestion.

The expected asymmetries in alpha were, as in experiment two, not obtained in the present experiment. Moreover, hemispheric differences were localised to two brain regions and their interaction with the type of group. Here, the control group showed greater right-sided temporal than frontal alpha activity (i.e. comparatively greater frontal activation) during presentation of the hot water stimulus while also showing greater right-sided temporal alpha activity to this stimulus than did the lunch group. The significance of these findings is unclear since this pattern would be expected in the contralateral hemisphere. It is possible, as suggested above, however, that these asymmetries may be a function of the type of stimulus used (namely, the hot water) which although rated the least alerting stimulus was something of a rogue, for the reasons outlined earlier. These findings may, therefore, not be odour-related.

#### *7.9.vi. Conclusion to experiments 1, 2 & 3.*

The experiments reported above suggest that exposure to odour may have a fairly direct effect on Central Nervous System functioning but that the psychophysiological consequences of meal ingestion are less pronounced. When these two variables are combined, as seen in the findings from the asymmetry indices, the effect of odour has been found to be dependent on the physiological state of the subject. It has been argued here, based on the findings from experiments two and three, that theta may be the dominant information-processing frequency for the perception of odour. This hypothesis, the evidence for it, and the theoretical framework which could possibly encompass it, is now assessed in the final chapter. The relationship between odour perception and human CNS activity is also considered together with the effect of food ingestion on electrophysiological behaviour. Implications for future research and suggestions for further investigations are presented.

## ~CHAPTER 8~

### ON EEG, EMOTION & ODOUR:

### A RE-ASSESSMENT & GENERAL DISCUSSION.

*"Results alone are not sufficient. There must be a framework within which to interpret them. There must be a theoretical paradigm."*

**D.A. Norman (1984)**

#### *8.1. Aims of the current thesis-revisited.*

The aims of the present thesis were three-fold and broad. As outlined in **Chapters 1 & 4**, the primary aim of the experiments reported here was to examine the effects of a common and "biologically relevant" olfactory stimulus, such as food odour, on Central Nervous System activity. Since little is known concerning the effects of exposure to odour on human brain activity, especially when compared with the cerebral effects of the "higher" senses, the principal objective was to demonstrate replicable electrophysiological changes, reflected in the EEG, as a result of natural olfactory stimulation. As noted in **Chapter 4**, clues as to the primary EEG frequency affected by olfactory perception are to be found in some of the published studies: The hypothesis was raised in the discussion sections of **Chapters 6 & 7**, that the most likely waveband to respond to olfactory stimulation is theta, with significant but less

pronounced effects in alpha. This hypothesis receives strong support from a number of other studies and will concern a large part of the remainder of this chapter.

The second aim of the thesis was also fundamental: the examination of the effects of food intake on electrophysiological behaviour, primarily on the ERP, but also on the spontaneous EEG (where effects have not been widely demonstrated). The ERP, and especially late, positive-going ERPs such as the P200 and P300, is known to be highly reflective of cognitive processing. The evidence reviewed in **section 4.8.** of **Chapter 4** suggests that this phenomenon may be altered by various experimental manipulations, including exposure to odour and food consumption. Reason would dictate that if changes in endogenous potentials (those presumably reflecting cognitive processes) occur with exposure to certain stimuli or under certain conditions, these conditions and stimuli may affect not only the appearance and form of the ERP but also the cognitive process which is hypothesised to underlie the ERP (such as attention and decision-making). Investigations of satiety argue that the greater ERP amplitude found when subjects' hunger is quelled is the result of increased attention (e.g., Stacher *et al.*, 1979). Whether this effect is the result of "psychological" factors such as feelings of satiety or due to physiological changes, such as alterations in brain metabolism is, as noted in the discussion in **Chapter 5**, unclear. It is argued here that while the consumption of food certainly produces changes in brain metabolism (as Geisler & Polich, 1992a, suggest), the increase in ERP amplitude may not necessarily be a consequence of this metabolic change. Rather, it is the satiety or experience of fullness produced by specific meals which alters brain metabolism (and also electrophysiological arousal) is the important factor in generating different evoked potentials.

The experience of particular stimuli was related to the third aim of the thesis. The discussion in **Chapter 4** suggested that stimuli of different affective valence are likely to produce significant differences in frontal EEG alpha asymmetry. Experience of pleasant visual stimuli have been associated with left frontal, anterior hemispheric EEG alpha activation; the emotion of disgust has been associated with increases in right frontal hemispheric EEG alpha activation, at least in some studies (see **Table 4.2.** in **Chapter 4**). The point was raised in **Chapters 6 and 7** that olfactory stimuli may or may not behave in a similar fashion to visual stimuli in generating different asymmetries of this kind. Davidson *et al* (1990) have argued, for example, that certain sensory stimuli such as auditory stimuli are not studied in this way since this type of stimuli may activate different brain regions or have other, non-affective features which might affect the outcome of the investigation such as pitch, tone, timbre and so on. Odours, however, are known to have reliable hedonic qualities. What is normally regarded as pleasant to one subject may not be pleasant to another but universal hedonic responses do exist, especially to familiar odours such as chocolate and to intuitively repellent odours such as excrement, rotting food, hydrogen sulphide, etc. (Rozin & Vollmecke, 1986). Related to the repellent nature of odour is the concept of withdrawal and approach behaviour which has been argued by some to have electrophysiological concomitants in the way of EEG frontal asymmetries (Davidson, 1984; 1992). While visual stimuli such as films may only be indirectly relevant to approach-withdrawal, however, smell is a much more potent and directly relevant stimulus. As noted in **Chapter 2**, the use of smell as a caveat under certain circumstances attests to its ability to repel and induce withdrawal. Food products such as meat, milk produce or vegetables which emit an unpleasant off-odour would not customarily be eaten by civilised societies. They invoke withdrawal behaviour. Whereas a pleasant odour will be sniffed repeatedly in order to prolong the enjoyment of the experience, an unpleasant odour will be approached in the opposite manner. Thus if any stimulus is capable of

inducing these two forms of behaviour- approach and withdrawal- odour should certainly be one of them. As noted earlier, if the EEG does reflect these two different behavioural processes, then repellent odours should show the right frontal hemisphere activation in alpha characterised by some disgusting visual stimuli. Conversely, pleasant odours should show an increase in alpha activation in frontal cerebral areas. In two experiments using odours which differed in quality and type, and with different recording protocols, this clear-cut pattern did not emerge. However, certain odour/affect-related asymmetries were obtained. The reasons for the lack of clear, hemispheric EEG alpha asymmetries, and for the particular asymmetries which were obtained, are discussed below. In addition, the findings obtained from the data relating to food ingestion will also be considered in the context of psychophysiology and negative alliesthesia. Of primary interest, however, is this relationship between olfactory perception and psychophysiological response. How relevant are the data from EEG studies to the understanding of the human olfactory system? Is the EEG a sensitive enough measure of olfactory information-processing? Can it be regarded as a measure of olfactory information-processing? Why are only certain EEG frequencies affected? And how can the findings reported here assist in the understanding of the neural correlates of olfactory perception?

### *8.2. EEG & odour II: The predominance of theta.*

In the review of the few studies of human EEG response to odour summarised in **Chapter 4**, it was possible to reach three conclusions regarding the current knowledge of human olfactory EEG. The first is that the experimental manipulation of odour presentation in these experiments has been very limited. In view of the affective properties of odour, for example, or the uncertain relationship between the sniffing nostril and its receiving cerebral hemisphere (Ehrlichman, 1986; Kobal, Hummel &

Van Toller, 1992), there appears to be considerable scope for applying EEG to these features.

Secondly, the EEG appears to be a reliable and valid method of measuring human electrophysiological, CNS response to odour. The EEG has been commended for its versatility in the measurement of various psychological variables from verbal and spatial reasoning to emotional response (Davidson, 1983). Its use in measuring response to sensory stimulation has also, although not very widely, been suggested. The averaged form of the EEG, the ERP has been especially useful in permitting the localising effects of somatosensory, visual and auditory stimuli although the recording of ERPs to olfactory stimuli has been less widely attempted.

Until recently, the relevance of the EEG to the measurement of human olfactory perception had not been considered, despite the increasing interest in mapping other sensory functions. Studies attempting to monitor EEG response to odour conclude that exposure to odour affects the pattern of EEG idiosyncratically and only in particular wavebands. Delta, for example, has not been reported to be susceptible to alteration by any olfactory stimulus in adult human subjects. The theta frequency, however, appears to be highly responsive to this kind of stimulus. This is, perhaps, the most intriguing conclusion that can be drawn from these studies. The strength of the relationship between olfactory perception and theta alteration suggests a specific role for this waveband in olfactory perception. First, however, the case against.

**8.2.i. *Objection 1: Other wavebands as well as theta appear to be affected by exposure to odour.***

In the studies reviewed in **Chapter 4**, analysis is usually undertaken in a small number of frequencies. Some studies select one waveband (Bushteva *et al*, 1958; Moncrieff,

1962; Kendal-Reed & Van Toller, 1992; Van Toller *et al.*, 1993), others have analysed two (Lorig & Schwartz, 1988) three (Stacher *et al.*, 1979; Lorig *et al.*, 1988; Lorig *et al.*, 1990) or four (Klemm *et al.*, 1992). Further differences in frequency selection arise when some studies distinguish waveband frequencies which differ from those of the classical wavebands. Lorig & Schwartz (1989), for example, distinguish between the alpha frequency and a Factor I waveband with a frequency of 5-8Hz which is almost analogous to the theta frequency. With this variety of wavebands, inconsistencies and idiosyncracies will arise. Of the eleven studies that have sought explicitly to examine the relationship between the perception of an odour and the pattern of EEG activity, three have analysed alpha only, one has analysed alpha and Factor I and six have included both the theta and alpha frequencies.

The effects of odour on EEG alpha have included desynchronisation and general suppression (Bushteva *et al.*, 1958; Moncrieff, 1962), no effect on alpha (Lorig & Schwartz, 1988; Lorig *et al.*, 1990; Klemm *et al.*, 1992), alpha reduction during undetected odours (Lorig *et al.*, 1991), "differences in the amount of alpha activity over left and right hemispheres" (Lorig & Schwartz, 1988, p.283) or slight alpha increases (Van Toller *et al.*, 1993). With the exception of the last study, all studies have reported either some diminution in EEG alpha as a result of exposure to odour or have found no effect of odour on this frequency. The findings from the earliest studies (Bushteva *et al.*; Moncrieff, 1962) may be disregarded on methodological grounds. No correction for eye-movement was reported and no statistical analysis was provided: Analysis was undertaken by visual inspection. Of two remaining studies which demonstrate alpha changes, one obtained the result to an undetected odour, the other employed a descriptive statistical technique (MDS) which may have produced different findings to those studies employing ANOVA. The remainder of these studies show no alpha effect.

The lack of alpha change is partly supported by the present experiments. In experiment 2, no effect of alpha, beta nor delta was obtained for any odour. In experiment three, however, a particular relationship emerged between the rotting meat and chocolate odours with the odour of chocolate showing greater alpha activity at bilateral occipital sites (thought to be the generating source of alpha) than did the odour of rotting meat. As suggested in **Chapter 7**, the hypothesis that alpha might reflect relaxed wakefulness suggests that the greater activity to the odour rated as relaxing and pleasing (chocolate) is possibly the result of the odour's psychometric property. Since the rotting meat was rated as the most alerting and least pleasant of the odours, less alpha during presentation of this stimulus when compared with the chocolate odour is not unexpected. The absence of the effect in experiment two, however, still requires explanation. Two possibilities arise: (i) the bilateral decrease to rotting meat is a fluke and an artifact or (ii) the odours demonstrating the alpha effect have some special properties which are not present in those used in experiment two. The first explanation is unlikely. The probability value for the effect was small for both electrode sites, O1 and O2. The bilaterality of the finding and the appearance of the effect at electrode sites hypothesised to overlie alpha's neural generators also argues against this explanation. The second explanation is more persuasive since the odours selected for experiment three were designed to be qualitatively different to those in experiment two. The earlier experiment involved the presentation of synthetic odorants which although fairly good analogues of the odour they were intended to re-create may not be regarded as completely natural odours. Those stimuli chosen for experiment three were intended to be as close to natural odours as possible, hence the use of cooked foods. If the human brain is likely to respond to any odour, then it might be expected to respond to the odour of items with which it is familiar and to which they have special meaning. Rotting meat was clearly a potent stimulus which contrasted greatly with the pleasant

smell of chocolate. In view of alpha's associations with relaxation (Niedermeyer, 1987; Schuman, 1980) the result is explicable. It could be argued, however, that alpha simply reflects levels of vigilance (Gastaut, 1974; Dongier, McCallum, Torres and Vogel, 1976; Ray & Cole, 1985; Perlini & Spanos, 1991) so that high levels of alpha presumably reflect a low degree of vigilance and low levels of alpha indicate a high degree of vigilance. This hypothesis is compatible with the findings reported in **Chapter 7**. The pleasant and relaxing quality of an odour such as chocolate, it could be argued, would be likely to produce less excitement and alertness than would an odour rated as less pleasant and relaxing. Such a negative odour would more than likely elicit some withdrawal behaviour, innervating the subject instead of calming and therefore increasing attentiveness. It is possible that such an explanation is appropriate and workable here.

Does the alteration of activity in one EEG band suggest that significant alterations in another are not possible or contradict the view that one band may be more significantly affected than others? It is unlikely. Most psychological variables measured by EEG elicit changes in a number of wavebands. The concept of desynchronisation is such an example. The interest lies in the particular bands which are affected and the electrode sites at which change occurs. Focus has remained on alpha and beta because these wavebands have been shown to be clearly affected by cognitive, perceptual and affective processing (Gale and Edwards, 1983; Davidson, 1988). Other waveband changes occur in tandem. Theta, for example, has also been implicated in EEG response during problem-solving and perception of complex stimuli (Schacter, 1977). The fact that some alteration in alpha has been found during exposure to certain odours does not undermine the hypothesis that another band is the frequency most susceptible to change during odour perception.

**8.2.ii. Objection 2: Changes in theta have been found in tasks which are not olfactory in nature.**

This objection would be valid if the theta frequency was argued to be affected by stimulation by olfactory stimuli only. Such an hypothesis, however, can be quickly disputed since tasks which do not involve olfactory stimulation produce alterations in theta (Mizuki, Masotoshi, Isozaki, Nishijima & Inanaga, 1980; Rugg & Dickens, 1982; Mizuki, Takii, Nishijima & Inanaga, 1983; Rappelsberger & Petsche, 1988). What is suggested is the tentative proposal that theta, to a greater extent than the other frequencies, is responsive to olfactory stimulation. It is possible that there are aspects of this stimulus, other than the quality of "smell", which generate theta changes (and these will be considered below) but the relationship between theta and olfactory perception is greater than that between olfactory perception and any other waveband (as seen above and in experiments two & three). Why, therefore, should theta be responsive to odour?

**8.3. Theta and olfactory perception: The case for.**

In the discussion of their findings, and in particular the result that four of the odours (jasmine, birch tar, lemon and lavender) used in their experiment were associated with increases in left anterior theta activity when compared to pre-stimulus baseline, Klemm *et al* (1992) suggest that there may be an association between the increases reported in theta and those associated with hypnosis and cognitive ability. The suggestion is based on Schacter (1977)'s review of EEG theta and psychological phenomena. The authors, however, do not go on to elaborate the details of what such a relationship should be or is but note that some odours have been found to have a positive effect on efficient cognitive performance (such as that reported by Warm *et al* (1991), see **Chapter 2**). Others have suggested that the changes in the EEG and in theta activity

accompanying odour presentation may mediate changes in subjective mood states (Lorig & Schwartz, 1988), although, again, no details of such a mechanism are given.

Experiments two and three also implicate theta in the perception of olfactory, food-related stimuli. In experiment two, strawberry was found to produce greater theta than spearmint at the right frontal region. In experiment three, chocolate was associated with less theta than any of the other odours (at FZ) and rotting meat was associated with less theta than a no-odour control at the left posterior site. Unlike the results of Klemm *et al* (1992) but in support of Stacher *et al* (1979) and Lorig & Schwartz (1988), all theta-related changes were comparative decreases in activity. An explanation for this discrepancy could lie in the methods of analysis employed in the present and other studies. Lorig & Schwartz (1988), for example, analysed data taken from three epochs during odour presentation, the present experiments compared an averaged epoch for each of the odours (including a no-odour control) during presentation only, whereas Klemm *et al* (1992) pooled activity during and after odour presentation and compared these data with those obtained during baseline, "pre-delivery" recording. Excluding the possibility of "odour quality" differences in each experiment which may have produced the effects reported, it is possible that the olfactory emphasis in theta may be the result of the activation of some other "psychological" process in which the olfactory stimulus is involved.

#### **8.4. Odour, problem-solving, task difficulty and theta.**

Changes in EEG theta have been associated with several factors including epilepsy (Ciganek, 1961), sexual orgasm (Cohen, Rosen & Goldstein, 1976), hypnagogic states (Schaacter, 1976), REM sleep (Rechtschaffen & Kales, 1968), problem-solving (Vogel, Broverman & Klaiber, 1968; Legewie, Siminova & Creutzfeldt, 1969; Ishihara & Yoshii, 1972; Dolee & Waldeier, 1974; Lang, Lang, Diekmann & Kornhuber, 1987;

Davidson, Chapman, Chapman & Henriques, 1990), perceptual processing (Daniel, 1967; Gale, Christie & Penfold, 1971; Gale, Coles & Boyd, 1971) and affective processing (Hoagland, Cameron and Rubin, 1938; Walter & Walter, 1949; Mundy-Castle, 1951; Ahern & Schwartz, 1985). Schacter (1977) notes that those studies of problem-solving which do result in theta changes normally report increases in activity. Similarly, the more complex the processing of a stimulus the greater the theta activity. He suggests that theta may be enhanced either due to "non-specific pre-stimulus increments in alertness or to task-specific operations". The first explanation is unlikely on the basis of the evidence available. An alternative suggestion is that these studies show that "selective, narrowly focused processing and intensive 'mental effort' are most consistently related to enhanced theta activity during problem-solving" (p. 59). More recent studies have also reported increased theta activity during the performance of repetitive mental arithmetic tasks (Miller, 1990) and during verbal and motor tasks (Lang, Lang, Dickmann, Kornhuber, 1987). This emphasis on focused processing is also suggested by the results of studies which have examined EEG responses to complex perceptual stimuli (e.g., Gale *et al.*, 1971).

The greater degree of theta activity found to some odours when compared with others, a finding reported in the present experiments and some other studies, suggests, in light of the "attention-processing theory" of theta responsivity, that the theta alterations witnessed in olfactory EEG experiments may be a function of attention and not due to the simple processing of an odour and its hedonic quality. This theory argues that the decreased theta to certain odours is a function of either the alertness of or attention paid to that particular stimulus. The theory is supported by a number of indirect findings. For example, as noted above, some studies have reported increases in theta during olfactory perception while others have reported decreases. This variation in theta responsivity appears to be unrelated to the affective quality of the odour although Lorig

& Schwartz (1988) associated the lower theta activity occurring during presentation of one odour with increased relaxation and decreased levels of anxiety on the basis of subjects' subjective odour ratings, arguably because this odour was perceived as less alerting which explains the change in theta activity. Klemm *et al* (1992) also report little correlation between odour pleasantness and degree of theta activity. The main effect of odour found in theta in the present experiments, however, indicates large variability. In experiment two, the odour rated as most pleasant, spearmint, was associated with significantly less theta activity than strawberry an odour rated as pleasant (scoring 3.68 to spearmint's 1.82 on a scale of 0-12.5). In experiment three, a moderately relaxing and pleasant odour, chocolate, generated less activity than the odours of baked beans, hot water, coffee and rotting meat at FZ, an electrode thought to show maximal theta (Ishihara & Yoshii, 1972; Westphal, Grozinger, Diekmann, Scherb, Reess, Leibling & Kornhuber, 1990). At the left posterior region, rotting meat, the odour rated as least pleasant, most alerting and most likely to make subjects unhappy, generated less theta activity than did a no-odour control. Thus on the basis of psychometric property alone, there appears to be no simple relationship between an odour's hedonic or affective quality and the odour's effect on theta.

If, however, theta reflects processing of complex stimuli and -by extension- the attention paid to complex and interesting stimuli, one might argue that greater attention would be paid to stimuli which the subject would be inclined to perceive as pleasant or one which allows the subject time to "examine" it, thereby increasing the amount of theta generated. Conversely, however, one could argue that an odour regarded as pleasant might be analogous to a simple cognitive task and might thus be associated with less theta activity than one which is analogous to a complex, 'strenuous' task. The unpleasantness of rotting meat, for example, would not invoke a great deal of attention because of its foul and distracting quality. The subject would consequently allocate

little time to perceiving the odour. A pleasant odour such as spearmint might be perceived at length, thus allowing the subject a greater period in which to appreciate the odour, its quality and possibly its associations [the evidence reviewed in **sections 2.4.i. & 2.4.ii.** of **Chapter 2** suggests that this may be the method by which certain odours have a beneficial effect on task performance such as that seen in Warm *et al* (1991)]. This hypothesis would appear to be partly supported by the finding that spearmint was associated with less theta than strawberry in experiment two and that chocolate was associated with less theta than all other odours in experiment three but not by the fact that rotting meat was associated with less theta activity than a no-odour control. However, it may be possible that some property of spearmint and chocolate is responsible for the low degree of theta they generate when compared with other odours. They are both pleasant and relaxing odours and their perception might be analogous to performing a simple cognitive or perceptual task. Very few demands are made on the subject's cognitive processes and although attention is paid to the stimulus the attention is not highly motivated as it would be in a complex problem-solving task.

Why, however, should significantly less theta activity be generated during presentation of rotting meat than during a no-odour control? It is possible that the degree of attention the subject pays during blank presentations is considerable. The subject is informed at the beginning of the experiment that an odour may or may not be present during each trial. The order of the odours is randomised and the no-odor control is always presented first although the subjects are unaware of this. It is highly likely that individuals may devote considerable attentional resources to this task during a blank trial since they may be expecting an odour to be present and are making a concerted effort at detection. The belief that there is a weak odour in the environment might additionally prompt this attentional executive into operation. The increased attention is thus reflected in high levels of theta activity. Alternatively, the rotting meat odour, as

argued above, might reduce the attention paid during its presentation since the subject may be distracted by its unpleasantness. With such lack of attention, decreases in theta activity might be expected. If both these hypotheses are correct then the finding for theta becomes explicable: attention paid during active detection (intensive task) is associated with greater degree of theta than the distraction caused by perceiving an unpleasant stimulus (simple task). Further investigation should establish the validity of the hypothesis.

#### **8.5. *Odour and EEG asymmetry: replication or re-modification?***

In the preceding section, the significance of the effect of odour on EEG was argued to be largely due to 'cognitive' rather than specifically olfactory factors. Yet, the affective quality of some odours has been thought to affect individual mood and cognition (Rotton, 1983; Rotton, Barry, Frey & Soler, 1978; Rotton, Frey, Barry, Milligan & Fitzpatrick, 1979; Baron, 1980; 1990; Knasko & Gilbert, 1990; Knasko, 1992). In EEG terms, some authors have sought to relate the changes in theta to the psychometric properties of the odour, as noted above (e.g., Lorig & Schwartz, 1988). Such a relationship, however, has been sought with little success.

Arguably, a considerable problem in the interpretation of the findings from studies of olfactory EEG to date has been the absence of a workable, theoretical framework. Part of this problem resides in the fact that little research on human EEG response exists. Consequently, the studies in this area, as in those of ERP discussed below, are largely results-driven: The data from one study are presented; another study attempts a replication with minor modifications and a clearer picture, it is hoped, emerges by placing these pieces of this mosaic together. In view of the affective nature of smell (as reviewed in **Chapter 2**), however, it is surprising that no research has, until now,

sought to relate odours of differing valence with EEG asymmetries, for which a tentative theoretical framework does exist.

This framework, as discussed in **Chapters 4, 6 & 7**, suggests that alpha asymmetry activation is a replicable electrophysiological concomitant of affective visual stimulus processing. Davidson and his colleagues have demonstrated such asymmetries in several studies using film and video clips (e.g., Davidson *et al.*, 1979; Davidson *et al.*, 1990; Ekman *et al.*, 1990; Tomarken *et al.*, 1990; Jones & Fox, 1992). It was argued in **Chapter 4** that, assuming all other factors are constant, similar asymmetries might be obtained using olfactory stimuli.

In fact, results from experiments two and three only partly support such a model and indicate that in order to explain affective processing adequately, slight but important modifications to this framework may be necessary. In experiment two, for example, no significant main effect of site nor odour, or any interaction was found between the food odours rated as most pleasant (spearmint) and least pleasant (garlic & onion) either in the alpha or the theta frequency. The reasons for the absence of clear, significant asymmetries may have in some way been related to the possibility that the odours were not adequately "relevant" (i.e. subjects were aware of the odour's synthetic quality) or to the possibility that the odours were not sufficiently extreme (even though the range from pleasant to unpleasant was 1.46 to 7.76). In experiment two, the odours were selected to be both relevant and definitive. Here, significant asymmetries were found for both the most pleasant (baked beans) and least pleasant (rotting meat) food odours but in separate wavebands. For example, more left-sided frontal activity was present to the baked bean odour when compared with the odour of rotting meat in the theta frequency. However, an intrahemispheric difference was found for the odour of baked beans in the alpha frequency where greater left-sided frontal activity than temporal

activity was found. In the context of Davidson's model, this finding is interpreted as greater temporal than frontal region activation during the perception of the most pleasant stimulus. This is broadly consistent with the EEG model of approach-withdrawal behaviour but the lack of a clear finding for the most unpleasant stimulus in alpha indicates several possibilities which may account for the model's shortcomings.

#### *8.6. Disparities & reasons for disparity.*

One possibility which arises from the negative findings reported here is that the type of stimulus used was inappropriate to the design and aim of the experiment and to the affect-EEG model in general. This is the extreme view. It states that any EEG difference which might be apparent in response to stimulation from one sensory modality will be different from that occurring with stimulation from another. As noted in **Chapter 4**, asymmetries in alpha would have been expected had olfactory stimuli behaved in a similar electrophysiological fashion to visual stimuli. However, there are significant anatomical differences between the organization and structure of these two systems which may have accounted for the absence of a cross-modal replication in alpha (Kandel & Schwartz, 1985). Recent evidence suggests that the right orbitofrontal and temporal cortex are heavily implicated in olfactory perception, discrimination and identification (Rausch, Serafetinides & Crandall, 1977; Abraham & Mathai, 1983; Eskenazi, Cain, Novelly & Mattson, 1986; Jones-Gotman & Zatorre, 1988a, 1988b; Zatorre & Jones-Gotman, 1991). Zatorre, Jones-Gotman, Evans & Meyer (1992), for example, using PET noted the unilateral activation of the right orbitofrontal cortex during a simple, odour sniffing exercise. Odour recognition memory has also been found to be impaired following right temporal or right orbitofrontal cortex impairment (Jones-Gotman & Zatorre, 1993) as has the retention of nameable odours in patients with epilepsy associated with the right temporal lobe (Carroll, Richardson & Thompson, 1993). Evidence from primate studies has implicated the lateral posterior

orbitofrontal cortex in odour discrimination impairment and in the perception of specific odours (Tanabe, Yarite, Iino, Ooshima & Takagi, 1975; Tanabe, Iino & Takagi, 1975). Potter & Nauta (1979) have also postulated an important corticocortical projection between the prohal region in the temporal lobe and the orbitofrontal cortex. Deficits in olfactory discrimination in rats has also been reported following orbitofrontal cortex lesions (Eichenbaum, Shedlack & Eckmann, 1980).

The ability to discriminate would thus appear to be dependent on the integrity of the right temporal lobe and also, to a large extent, on the orbitofrontal cortex although bilateral and unilateral lesions to this area produce discrimination and identification deficits. If these areas are involved in the specific ability to discriminate between odours and recognise odours then activation at these locations, in view of the site effects found in the PET study noted earlier, might be witnessed in similar areas by the on-going EEG. In fact, only one such effect was found. In experiment three, there was a significant effect of electrode site in alpha for the baked bean odour. Greater left-sided activation was noted at temporal than at frontal sites. The parsimony of this finding suggests that, in spite of the orbitofrontal involvement in the olfactory system, the presumed cortical site of olfactory processing is not clear on the basis of EEG recording. It should be noted, however, that the experiment was not a direct investigation of localisation of olfactory function but was concerned with possible affective EEG asymmetries in olfactory processing. More suitable designs might demonstrate significant task differences in the EEG according to electrode site. The question then remains as to what specific function the temporal lobes serve in olfactory processing since these areas are also known to be involved in memory for other sensory modalities (Milner, 1978; McCarthy & Warrington, 1990; Samson & Zatorre, 1992). Carroll *et al* (1993) suggest that since olfactory perception involves components of autobiographical memory, then the likely site for recognition impairments in

olfactory processing would be the temporal lobes whose damage is associated with global amnesia (McCarthy & Warrington, 1990). Such an hypothesis has not been tested. In view of the orbitofrontal involvement in odour perception, however, the lack of alpha frontal asymmetry in experiments two and three is puzzling. If the right orbitofrontal cortex is an important cortical site, it is surprising that the effects found in experiments two and three were not more widespread. Hardly any significant effects at this site between a no odour control and the odour were reported.

A less controversial alternative to the extreme interpretation - a modification to the model - is that affective, olfactory asymmetries may be reflected in the EEG but only by particular odours and in a waveband other than alpha. It is clear from the previous sections that theta is particularly influenced by olfactory stimuli. If any waveband is to show significant asymmetries to odours of opposing valence, therefore, one might expect theta to do so. In fact, the finding from experiment three that greater frontal left-sided theta activity was present to baked beans than to rotting meat supports such an hypothesis. Theta asymmetries are not uncommon and have been reported for cognitive (e.g., Rappelsberger and Petsche, 1988) and affective tasks (Ahern & Schwartz, 1985). The locus of the EEG asymmetry found for the odours in theta was the frontal region a finding which is at least in keeping with the geographical spirit of the affect-EEG model.

Another possibility that must be considered is that there were serious methodological differences between the present studies and those of Davidson and his colleagues. To begin, EEG recording in Davidson's experiments occurred with the subject's eyes open. In all the experiments reported here, subjects' eyes were closed and their hearing (in the EEG studies) was limited. This difference although posing no threat to adequacy of recording (Davidson *et al* employ adequate artifact removal procedures; the

films used had the sound removed), suggests that the visual nature of stimulus processing may have accounted for the discrepancy. The visual modality provides a considerable degree of information to the perceiving organism and may provide a greater fillip to imagination that might for example, an olfactory system processing a single odour. The fact that subjects watched moving stimuli in the visual affect studies, involving a degree of cognitive engagement, may have contributed to the differences between the studies. However, in view of the psychological correlates of theta activity discussed above, one might have expected, if EEG activity is affected by intense cognitive engagement and attention, asymmetries to occur in this frequency. Davidson *et al.*, however, do not normally analyse activity in this frequency. Whether any effects in theta were obtained, therefore, is unknown.

Indirect evidence to support the "attention" hypothesis is found in the findings from experiment one. In **Chapter 5** (section 5.9.iii.), it was suggested that the odours employed reflected a hierarchy of distractability so that some stimuli would be more alerting or distracting than others and would, therefore, produce differential effects on ERP amplitude. In experiment one, a significant odour-related diminution of P200 amplitude was found to the odour of strawberry when compared to a no-odour control. The odour of vegetable, similarly, was associated with significantly smaller P200 amplitude than the odour of coffee. The odours of strawberry and vegetable represented the extreme ends of the hedonic dimension- one pleasant, the other unpleasant. The hypothesis suggested in **Chapter 5** and above is that the unpleasantness and distractability of an odour are highly associated and may exert similar perceptual effects. For example, a number of studies has found poor cognitive performance during exposure to "negative" olfactory stimuli (Lewis *et al.*, 1970; Rotton *et al.*, 1979). These studies and others reviewed in **Chapter 2** suggest that it is the odour's unpleasantness which distracts the subject from the task being undertaken.

No study has yet considered a systematic investigation of this hypothesis although the indirect evidence that is available and the literature from ERPs and attention would suggest that there is considerable support for such an interpretation.

A recent paper has argued that the late positive-going wave recorded during an auditory oddball paradigm may be associated with increased attention on the part of the subject (Basar-Eroglu, Basar, Demiralp & Schurmann, 1992). This investigation recorded ERPs and EEG delta and theta simultaneously and found that during increased attention, significant increases in theta were recorded in frontal and posterior locations. The link between increased attention and late positive-going waves such as the P300 is not novel and has been suggested elsewhere (Woods, 1990). The association between an ERP component known to be related to attention with significant increases in theta, however, is of greater interest since it would confirm the hypothesis presented above that the theta frequency is a putative index of attention. Furthermore, it was suggested above that odours exhibit different degrees of distractability: the greater the distractability the lower the ERP amplitude. This, in fact, was observed. Considering the data from the EEG and ERP studies together, therefore, a strong argument may be put forward that electrophysiological effects associated with exposure to odour might be mediated by some form of attentional executive which has its primary EEG manifestation in the theta frequency.

#### *8.7. Food ingestion, olfactory perception and the EEG.*

The second aim of these experiments had two elements. The first element concerned the relationship between the individual's response to food odour following lunchtime meal consumption in the context of negative alliesthesia (Cabanac, 1971). The second

element was related to the individual's EEG response to food odour after the ingestion of a lunchtime meal.

*8.7.i. Olfactory alliesthesia: a viable construct?*

On the basis of the three experiments undertaken here the concept of negative olfactory alliesthesia does not appear to be robust. In not one of the experiments did the hedonic rating of the food odours differ between fed and unfed subjects. In experiment one, it was suggested that a larger range of odorants might be necessary in order to demonstrate an effect of alliesthesia. Also, since the odours were rated once only and after the second EEG session, the interval between ingestion and the rating may have been too long. In experiments two and three, the psychometric ratings were made both before and after the inter-session interval. Even with these modifications, no effect was observed. Furthermore when the odours of real food (and odours of food used as part of the experimental lunch) were used as rated stimuli, the negative trend of these results was further heightened. The reasons for the absence of an effect have been considered in detail in **section 7.9.i. of Chapter 7** and will not be repeated here. It is sufficient to suggest, however, that on the basis of the studies undertaken here, the notion of olfactory alliesthesia does not appear to have strong validity.

Given this finding, no post-prandial differences in EEG asymmetry between the lunch and control groups would be expected, based on odour pleasantness. This prediction was partly supported by the findings from experiments two and three. In experiment two, no expected frontal asymmetry differences between the control and lunch groups was obtained in alpha, perhaps not altogether surprising given the absence of any relevant, significant odour effects in the alpha frequency in this experiment. The control group did, however, show greater overall left-hemisphere alpha activity than did the lunch group and also showed significantly greater left-hemisphere activity to the

odours of spearmint and garlic and onion than did the lunch group. The difference in alpha asymmetry in experiment three, however, was restricted to the EEG response to the odour of rotting meat. In this experiment, the control group exhibited greater relative right-anterior temporal EEG alpha activity to this odour, compared with the activity of the lunch group. In view of the hemisphere in which one might expect to respond to an offensive odour, this finding is illuminating. It is possible that the controls found this odour more offensive than the fed group at the second presentation although the lack of a group x pleasantness interaction for the psychometric scores suggests that this is unlikely. Another possibility, however, is that the metabolic effect of ingestion rendered electrophysiological response to offensive stimuli less receptive, perhaps due to the reduction of the motivational drive for food or nonchalance towards the offensive food-related stimulus engendered by satiety. The controls, having no such motivational or metabolic restrictions, perceive and respond to the odour as before with the net effect that EEG activity in the right hemisphere increases. This interpretation clearly warrants further investigation.

**8.7.ii. *The electrophysiological response to food consumption.***

A small number of studies reviewed in **Chapter 4**, suggests that the amplitude of the ERP, and especially the amplitude of P300, depends on recency of ingestion. From the evidence available from ERP and food analogue studies, it was hypothesised that an interaction might occur between recency of food consumption and exposure to food odour so that fed, satiated individuals would show larger amplitude ERPs during exposure to food odour than would hungry individuals. As noted in the previous section, however, the expected decrement in the hedonic ratings for food odours in unfed subjects was not found. These predictions relating to psychophysiological response were partly supported by the findings reported in experiment one. The amplitude of the P300 remained unaffected by the presence of odour, by the ingestion

of lunch or by time-of-day, a surprising lack of alteration given the effects obtained elsewhere for P300 (Kerkhof; 1980; Geisler & Polich, 1992a, b; Lorig *et al*, 1991). Possible reasons for this inconsistency have been discussed in some detail in **Chapter 5**. Apart from methodological differences, there may have been differences in interpretation between the Geisler & Polich studies which showed increased P300 amplitude with recency of food intake and the present experiment. These authors associate the amplitude changes reported in their study with metabolic changes resulting from food ingestion. The present thesis argues, however, that it is not the metabolic alteration *per se* which effects this change in ERP size but the subjective feeling of satiety the subject experiences. The former studies did not employ any measure of satiety or hunger in order to rule out any possible effects of subjective measures. It is perhaps these subjective experiences which are responsible for the effects found for P200. As noted in **Chapter 5**, it is possible that the P200 and P300 components overlap significantly and that what has been obtained in the present experiment is, in fact, an effect on P300. In view of the amplitude selection procedures undertaken, however, this appears possible, although unlikely. The significant interaction between group, odour and time-of-day found at CZ for P200 certainly mirrors that found elsewhere for P300. Target P200 was significantly larger in the lunch group post-prandially than pre-prandially, a finding which indicates that recency of food consumption is able to alter the size of a late potential. Geisler & Polich (1992a) reported small increases in the P200 of fed subjects and suggested that the effect of ingestion may be general rather than specific to the P300. More interestingly, and in support of Stacher *et al* (1979), a significant three-way interaction was also obtained at FZ for target P200. At this site, the control group showed a significant decrease in amplitude to the vegetable odour in the afternoon which does suggest that a food odour is capable of altering the electrophysiological behaviour of an unfed subject but not a fed subject. The finding, in fact, lends indirect support the hypothesis that a hungry,

unfed subject would be more easily distracted by the presence of food odour than would a satiated, fed subject. The amplitude of the P200 and P300 is known to be affected by diminished attention (Courchesne *et al*, 1978). Experiment one has demonstrated for the first time that such a diminution can be obtained in unfed subjects participating in an experiment administering natural foods and employing stimulation by food odour, complementing different studies using food analogues and extraneous stimuli such as the noise and smell of food preparation and other EPs such as the N200 (e.g., Pietrowsky *et al*, 1989).

The effect of meal consumption on the spontaneous EEG in the present experiments was variable. In experiment three, the lunch group showed significantly higher levels of alpha activity during the second, (post-prandial) session, than the first (pre-prandial). In view of the nature of alpha and its associations with relaxed wakefulness, this finding might indicate a greater relaxation in those subjects who had fed and whose hunger has been quelled. The results from experiment two, however, appear contradictory. In this experiment, control subjects showed the same general pattern of alpha activity. This finding indicates two possibilities. The first is that little reliability can be attached to the spontaneous EEG as a measure of satiety. This extreme view is supported by the result that over two testing sessions, two different samples of subjects gave contradictory responses. However, this possibility also raises another, methodological possibility, namely, that the two groups differed significantly in some way. Subjects in both experiments were issued with the same instructions regarding food consumption. All subjects were told to refrain from eating or drinking three hours before the beginning of the experiment. The testing protocol was virtually identical in both studies. There were *minor* differences between the two studies, however. The standard meal eaten by the lunch group in experiment three contained one item not present in experiment two. Although possible, it is highly unlikely that the inclusion of

this item, chocolate mousse, would have dramatically altered the outcome of the experiment. The EEG recording period for experiment three was extended to 30 epochs (2.56 seconds. x 30) per trial compared with 15 recorded during experiment two. It is possible that this greater sampling of the EEG may have produced a more reliable measure of brain response in experiment three. The ingestion of a meal is unlike the presentation of an odour or a tone. The length of time required for brain metabolism to alter may vary. As an event such as meal consumption is not time-locked, it may appear necessary to record longer samples of EEG in order for an effect of ingestion to manifest itself. If this hypothesis is correct, then the interpretation given of the alpha effect in the lunch group is plausible on two counts. First, it is plausible because of alpha's assumed relationship with relaxation and wakefulness and second, it is plausible because a more reliable EEG recording sample was analysed.

Of some note is the significant time-of-day effect found in all three experiments. In both the EEG studies, time-of-day was found to be significantly associated with increases in alpha activity during the second session (p.m.). What is of even greater interest is that this finding was replicated in experiment three and at the same electrode location (PZ). The alteration in alpha reported in two spontaneous EEG studies would suggest that the EEG may be sensitive to individual diurnal changes (either in temperature or some other unknown psychological variable) and may be indexed by a particular electrode site. As discussed in **Chapters 6 and 7**, however, whether these changes truly reflect diurnal "circadian" variation is uncertain. A longer recording period than that used in the present studies would be required in order to examine more carefully the changes in EEG over-time, using other physiological indices such as blood glucose level and body and oral temperature. Kerkhof (1982), for example, reported a trend for oral temperature as well as the P190 ERP component to increase from 9 a.m. to 9 p.m., a finding the author attributes to a general arousal mechanism.

Others have noted diurnal increases in body temperature (Colquhoun, 1971). Comparing these various factors by measuring them comprehensively in tandem will clarify the role of diurnal variation in physiological change.

#### *8.8. Conclusions & future considerations.*

The findings of the present experiments confirm a number of previous observations regarding olfactory perception and human EEG response. They have highlighted specific EEG activity changes which occur during olfactory stimulation and also suggest that food ingestion has a significant effect on brain electrophysiology.

The most prominent finding concerned the susceptibility of the theta frequency to food-related olfactory stimuli. In the second experiment no other waveband but theta appeared to show a significant effect of odour. In experiment three, other wavebands showed significant, but not widespread effects of odour. The EEG results together with the evidence from olfactory psychology reviewed in **Chapter 2**, suggest that the odours affecting theta activity produce the observed alteration via greater distractability. In **Chapter 2** it was argued that performance deficits observed in tasks completed in the presence of an unpleasant odour were related to the degree of attention given to the task. Offensive odours might thus cause significant distraction from the exercise resulting in poor task performance. The relationship between theta activity and degree of attention (especially focused attention as witnessed in EEG studies of perceptual and cognitive processing) suggests a model whereby theta activity is explicitly affected by the psychometric property of the odour. Thus, in olfactory cognitive experiments, more errors are made on tasks requiring attention when subjects are exposed to unpleasant, distracting odours (Rotton, 1983). Increases in attention are evident when the odours are perceived and rated as quite pleasant (Warm *et al.*, 1991; Baron, 1990). Given that theta activity increases are associated with increased focused attention, the

results found in the present experiments suggest that it is this focused (or non-focused in the case of unpleasant olfactory stimuli) attention which results in the alteration of the pattern of activity found in theta. However, as discussed earlier, this relationship between theta activity and olfactory perception is related not only to the type of odours used but also to the properties of these odours. A hierarchy of influential odours is proposed whereby some stimuli will generate greater theta activity increases than others, depending on their distractability.

The effect of odour valence on EEG activity is less obvious. The expected frontal asymmetries in alpha were not obtained in the second experiment but were present in the third experiment in which the odours of real food (in this case, the odour of baked beans was associated with greater frontal left hemisphere EEG alpha activation than left temporal activation) were employed. Most odour-related asymmetries were obtained in theta which is consistent with the hypothesis that the theta waveband is the principal frequency for the transmission of olfactory information. One method of comprehensively examining the relationship between affect and EEG alpha asymmetry is by comparing EEG responses to stimuli from different modalities directly within the same experiment: audition, vision and olfaction, for example. As noted in **Chapter 2**, however, such an experiment would require the stimuli to be equated in order to rule out some "verbal" or "nonverbal" superiority of one over the other which might affect the outcome of the experiment. Provided that it is possible to equate these types of stimuli for psychometric properties, a study such as this would elaborate more clearly the cross-modality nature of affective response if, in fact, such cross-modality interactions exist.

The ingestion of food was found to alter the course of the spontaneous EEG in erratic ways. For example, in experiment two, controls showed less alpha activity in the

morning than in the afternoon whereas an identical pattern was found in experiment three but for the lunch group. As considered above, however, this difference may have been due to the length of EEG recording chosen for analysis. It is reasonable to argue, however, that the ingestion of a lunchtime meal in the experiments reported above had no reliable effect on the spontaneous EEG.

In contrast to spontaneous EEG measures, the ERP appeared particularly sensitive to recency of food ingestion. A significant increase in P200 amplitude was observed in those subjects who had eaten when compared with those subjects who had not. The significance of this increase may be related to the subject's attentional resources whose distribution the P200 is thought to reflect. The mechanism for the ingestive effect on P200, however, is not clear. In a previous section, the suggestion was made that it is not the metabolic changes occurring with ingestion *per se* which are responsible for the changes in the ERP but the subject's affective state following ingestion. Thus the comfort of satiety might enhance the attention of subjects in a task in which simple attentional resources are required. This is in accordance with Smith's (1992) conclusion that performance deficits following lunchtime ingestion are seen primarily in tasks requiring sustained attention and infrequently on shorter exercises. This increased attention following satiety may also be responsible for the larger P200 found in fed subjects exposed to the odour of vegetable than in unfed control subjects. Although studies employing food analogues and an assortment of food-related stimuli (noise of food preparation and cooking as well as food odour) in non-oddball, simple auditory evoked potential investigations have reported similar increases in the N1-P2 in satiated subjects during the presentation of these food stimuli, the results reported here are the first to demonstrate such an effect in subjects consuming normal meals and exposed to odour only.

Results from the studies of alliesthesia are not particularly supportive of an olfactory analogue to negative gustatory alliesthesia. No evidence of negative olfactory alliesthesia was found in any of the studies despite several manipulations in which the potential for producing alliesthesia was maximised. It is possible that procedural differences between the studies reported here and those reported elsewhere may have determined the negative observations recorded. The time-scale between the first rating session and feeding/fasting and the first rating session and the second rating session is comparable to the closest experimental design reported elsewhere (Duclaux *et al.*, 1973). In Duclaux *et al.*'s experiment negative alliesthesia for food odours reached a maximum 60 minutes after food consumption and diminished in the following 60 minutes. In experiments one and two of the present study, subjects rated the odours approximately 30 minutes after consuming/fasting. In experiment 3, subjects rated the odours 5 minutes after consuming lunch in order to establish a more rigorous test of alliesthesia. The reports of negative olfactory alliesthesia reported in other studies (e.g., Cabanac & Fantino, 1977) may be explained by the satiating methods used. In the Cabanac studies, for example, gastric or duodenal injections of glucose or nonabsorbed sugars are administered directly by the subject. As noted earlier, however, this may not reflect the genuine experience of eating or of satiety. It is possible that negative alliesthesia was not observed due to the types of odour used and it is arguable that caution should be invoked before concluding that the notion of negative olfactory alliesthesia may be solely an experimental artifact. Although a range of sweet and savoury food odours along with non-food odours were rated, the findings presented here do not exclude the possibility that other specific odours might elicit different hedonic responses. It should be worthy of note, however, that although the pleasantness ratings of these odours were not affected by the ingestion of lunch, the ability of these odours to evoke feelings of hunger was. Post-prandially, food odours were less likely to elicit hunger than pre-prandially. Thus, it is perhaps not the hedonic response that studies of negative

olfactory alliesthesia are investigating but a much more simple but closely related concept- the ability to induce hunger. This hypothesis is consistent with existing knowledge regarding post-ingestive physiology (Cabanac & Fantino, 1977). On the basis of the ratings of the odours employed in the present experiments, however, olfactory alliesthesia may not be as robust a phenomenon as gustatory alliesthesia.

Taken together, these experiments indicate that olfactory stimuli are able to affect the pattern of Central Nervous System activity directly and indirectly. The principal information-processing frequency for olfactory stimuli would appear to be theta, a waveband known to be affected by tasks requiring focused attention. The principal ERP component which may be affected by exposure to olfactory stimuli is the P200, a component known to reflect simple attention. This ERP component also appears to be a more reliable index of satiety than the P300, a finding which may be explained by the distribution of attentional resources which this component is thought to reflect. The finding further indicates that certain precautions regarding subject's nutritional status need to be considered before individuals participate in ERP studies.

The hypothesis that theta is altered by focused attention and the distractability of odour requires further investigation. For example, one experiment might involve a comparison of the EEG activity during performance of a complex, perceptual or problem-solving task requiring such attention with that during the perception of particularly complex and distracting odours. The only marginally related study to date has focused on the comparison between the EEG activity during the imaging of a favourite food and during the performance of relaxation imagery and mental arithmetic (Lorig & Schwartz, 1988). A more specific study might assist in elaborating not only the psychological significance of theta but also the significance of odour in the modulation of EEG frequencies.

It may be arguable, of course, that nothing of value is really learned about the attentional or hedonic mechanism in humans by using these measures that other less complicated, behavioural measures might not detect. It is important, however, to distinguish two types of response, similar in fact to the Watsonian dichotomy of implicit and explicit responses. Data from explicit, behavioural, observable measures may give an adequate index of the subjective experience of the individual. The aim of the psychophysicologist, however, is to understand the neural mechanisms underlying these subjective states and behavioural phenomena. Although a crude measure of psychophysiological activity, the EEG provides a means of examining subjective states in a more objective fashion. The combination of EEG recording and psychological manipulation may also help explain the more general problem of what EEG traces mean. Are they reflective of particular emotional, motivational or behavioural states? Are they merely the plumes of some extinguished sensory fires (as Moncrieff using a different metaphor has suggested), reflective of an alteration brought about by general sensory stimulation? Evidence accumulated thus far indicates that the 'generalisation' hypothesis may not be the correct one. A number of other studies relate specific EEG changes to specific psychological manipulations. However, the precise psychological significance of the EEG is unknown. Data presented in the experiments reported here suggest that one particular waveband may mediate a human organism's attentional processes, thus suggesting an electrophysiological substrate of a psychological phenomenon. Such discoveries are the aims of psychophysiology. While acknowledging the importance of subjective, behavioural data, psychophysiology is concerned primarily with relating such data to internal physiological states. The EEG provides a peep-hole for observing those physiological states in the brain.

The EEG may be a workable psychophysiological measure of cognition, perception and the affective processing of visual stimuli, however, but a more direct study of the effect of odour valence might be undertaken using MRI. A recent PET study has demonstrated unilateral significant increases in activity in the right orbitofrontal cortex in human subjects during olfactory perception (Zatorre *et al.*, 1992). The authors argue, on the basis of previous investigations, that this finding adds support to the hypothesis that strong olfactory connections are present in this area of cortex. Perhaps this technique might be a more effective method of investigating frontal brain asymmetry during perception of odours of opposing valence than is the EEG. There is also great potential for such a method to elaborate the function of structures in the limbic system such as the amygdala and hypothalamus in the perception of olfactory stimuli (Watson *et al.*, 1992) as well as more functional olfactory structures in healthy and unhealthy subjects (Yousem, Turner, Cheng, Snyder & Doty, 1993). A study has yet to be undertaken comparing the effects of pleasant and unpleasant odours during MRI but an exploration is clearly justified.

The results from the ERP study are clearly interesting and warrant further investigation. The hypothesis that odour is perceived along a dimension of distractibility has been discussed in relation to the effect of olfactory stimuli on the theta frequency. It is also relevant to the ERP literature since a distracting sensory stimulus may radically affect the manifestation of particular components. The absence of an effect for P300 in this experiment suggests that olfactory stimuli behave in different ways than other distractors (such as secondary tasks) perhaps because these other distractors require more cognitive processing resources than do odours. This would suggest that the P200 is affected by stimuli which are not weighted heavily on some cognitive component but but by those which are sufficiently engaging to alter electrophysiology associated with cognitive or attentional engagement. As noted above, interpretation and theoretical

implications in ERP and EEG studies are largely data driven. In the EEG domain, there are some models available which may be tested methodically and empirically. Davidson's model of affective processing, for example, was explored in experiments two and three. However, it is only by discovering new variables capable of influencing brain behaviour that a better picture of cerebral functioning can be obtained.

There is a caveat in the findings reported here which should be of concern to ERP and EEG investigators. In light of these findings, it would be advisable to monitor the food intake of subjects prior to ERP testing in order to ensure that all subjects are of identical nutritional status. Instructions to such effect could be administered prior to testing. It is arguable that many of the inconsistencies found in the EEG and ERP literature are the result of unconsidered variables such as recency of food ingestion. Furthermore, the use of odour in electrophysiological testing environments should be observed and controlled very closely so that these stimuli do not affect the recording. In view of the findings reported here regarding odour distractability and those elsewhere reporting EEG effects accompanying the presentation of odours of low concentration (Lorig et al, 1990; Lorig et al, 1991), caution in the use of olfactory stimulants is recommended in the EEG environment.

In conclusion, the findings reported here suggest that olfactory stimuli may affect EEG activity consistently. The primary channel for the transmission of information regarding aspects of olfactory perception would appear to be the theta frequency, a waveband which has been shown to be influenced by the presence of odour. Further investigation of the ways in which this frequency is affected by other variables will provide a clearer picture of theta function, if theta in fact has a specific function. Olfactory stimuli may also affect more gross measures of brain electrophysiology thought to reflect simple attentional resources, such as the P200 component of the

auditory oddball task. Furthermore, satiety in combination with olfactory perception may also significantly affect this component. Unfed, hungry controls exposed to the odour of food manifest shorter P200 amplitude than fed, satiated subjects. The finding indicates that the attentional resources of satiated subjects may be greater than those of hungry subjects. Clearly, this finding is worthy of further investigation.

At the end of **Chapter 4**, Moncrieff's cautious remarks regarding the interpretation of the EEG were invoked. Moncrieff adopted a sceptical view of the significance of the EEG, understandably given the relatively unsophisticated EEG equipment and data analysis which was utilised at the time. The advancement of EEG technique, method and investigation has resulted in a greater ability to explore the significance of the EEG to human behaviour. Its application to studying aspects of human olfactory perception has been reported elsewhere and is demonstrated in the present experiments. In tandem with other techniques such as neuropsychological assessment and Magnetic Resonance Imaging, the EEG may provide an effective, complementary aid to observing the function and operation of the brain and how it processes odour. As Lorig (1989) noted, "the nature of human odor response remains fascinating and elusive but the development of new EEG techniques offers promise for its eventual resolution."

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**~APPENDIX A~**

**Maps illustrating changes in the EEG**

## LEGENDS FOR FIGURES IN APPENDIX A

**Fig. A1** illustrates electrodes showing differences in target P200 amplitude following odour presentation. The no-odour control showed a greater amplitude than the odour of strawberry at FZ, the odour of strawberry was associated with greater amplitude than the odours of lemon and vegetable at TCP1, and greater amplitude was found for the odour of coffee than vegetable at TCP2.

**Fig. A2** illustrates those electrodes showing time-of-day differences in standard P200 amplitude. Larger amplitude was obtained in the afternoon than the morning at C4.

**Fig. A3** illustrates those electrodes showing an odour x group x time-of-day difference in target P200 amplitude. The effect at FZ is attributable to lower amplitude in the control group during exposure to the odour of vegetable in the afternoon when compared with the lunch group. The effect at CZ is attributable to significantly greater P200 amplitude in the lunch group in the afternoon than in the controls.

**Fig. A4** illustrates the electrodes showing a time-of-day effect for target N100 latency. Latency was significantly longer in the afternoon at FZ.

**Fig. A5** illustrates electrodes showing odour x time-of-day differences for target N100 latency. Larger latency was significantly longer in the afternoon than the morning at F3 during exposure to the odour of vegetable.

**Fig. A6** illustrates electrodes showing time-of-day effects for target P200 latency. Latency was shorter in the afternoon than the morning at FZ.

**Fig. A7** illustrates electrodes showing time-of-day differences for P300 latency. Latency was longer in the afternoon than the morning at F3 and F4.

**Fig. A8** illustrates electrodes showing changes to odour in the theta frequency in experiment 2. Strawberry odour was associated with significantly greater theta than spearmint odour at F8.

**Fig. A9** illustrates electrodes showing time-of-day differences in the alpha frequency in experiment 2. Significantly greater alpha activity was seen to be generated in the afternoon than the morning at PZ.

**Fig. A10** illustrates electrodes showing an effect of odour in the alpha and theta frequencies in experiment 3. Chocolate odour was associated with significantly greater theta activity than was any other odour at FZ; the odour of rotting meat was associated with less theta activity when compared with a no-odour control at T5. At O1 and O2, significantly greater alpha was associated with the odour of chocolate than the odour of rotting meat.

**Fig. A11** illustrates electrodes showing time-of-day differences in the theta, alpha, beta 1 and beta 2 frequencies in experiment 3. A significant increase in theta activity was found in the afternoon than in the morning for F7 and T3. A significant p.m. decrease was found in this waveband at FZ. PZ showed increased alpha activity in the afternoon. Greater beta 2 activity was observed in the afternoon at T3 whereas less beta 1 activity was observed in the afternoon for the same electrode.

**Fig. A12** illustrates electrodes showing odour x time-of-day changes in experiment 3. Significantly less alpha activity was associated with the odour of chocolate in the afternoon than the morning at FZ. Greater beta 2 activity was observed for the hot water stimulus in the afternoon than the morning at CZ.





LEFT

RIGHT

Fig. A3

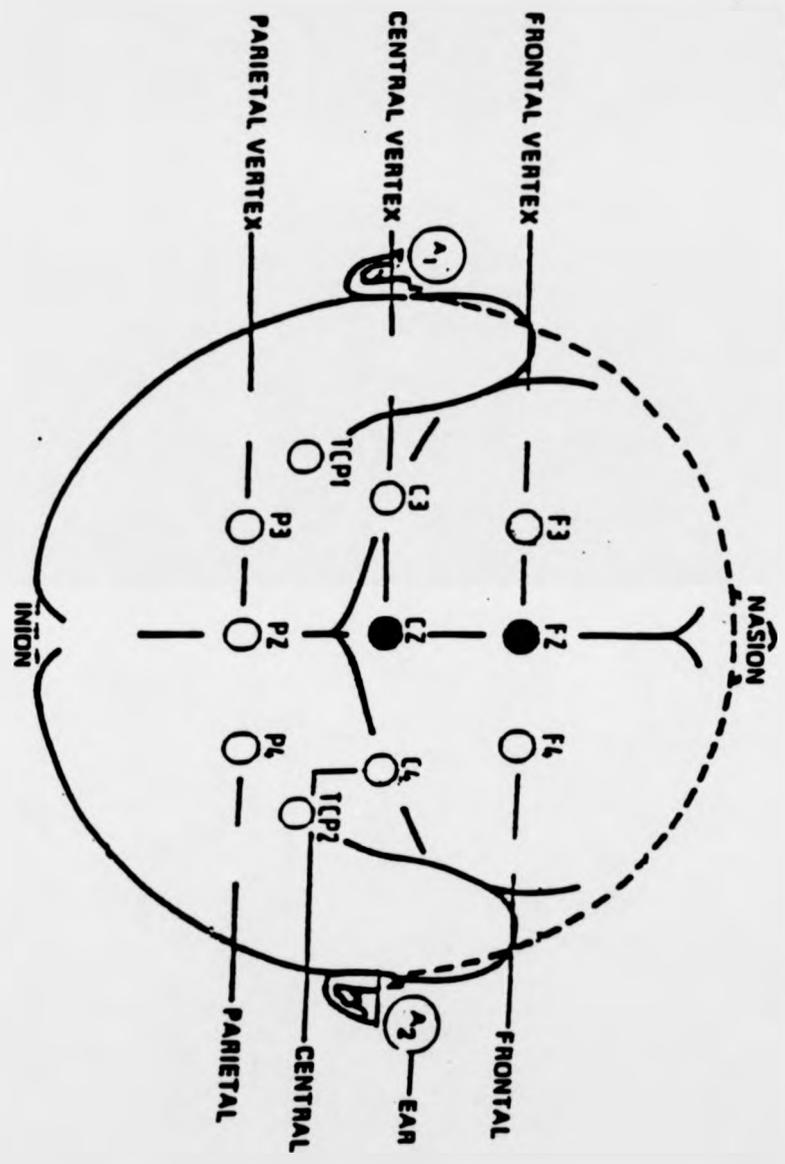




Fig. A5

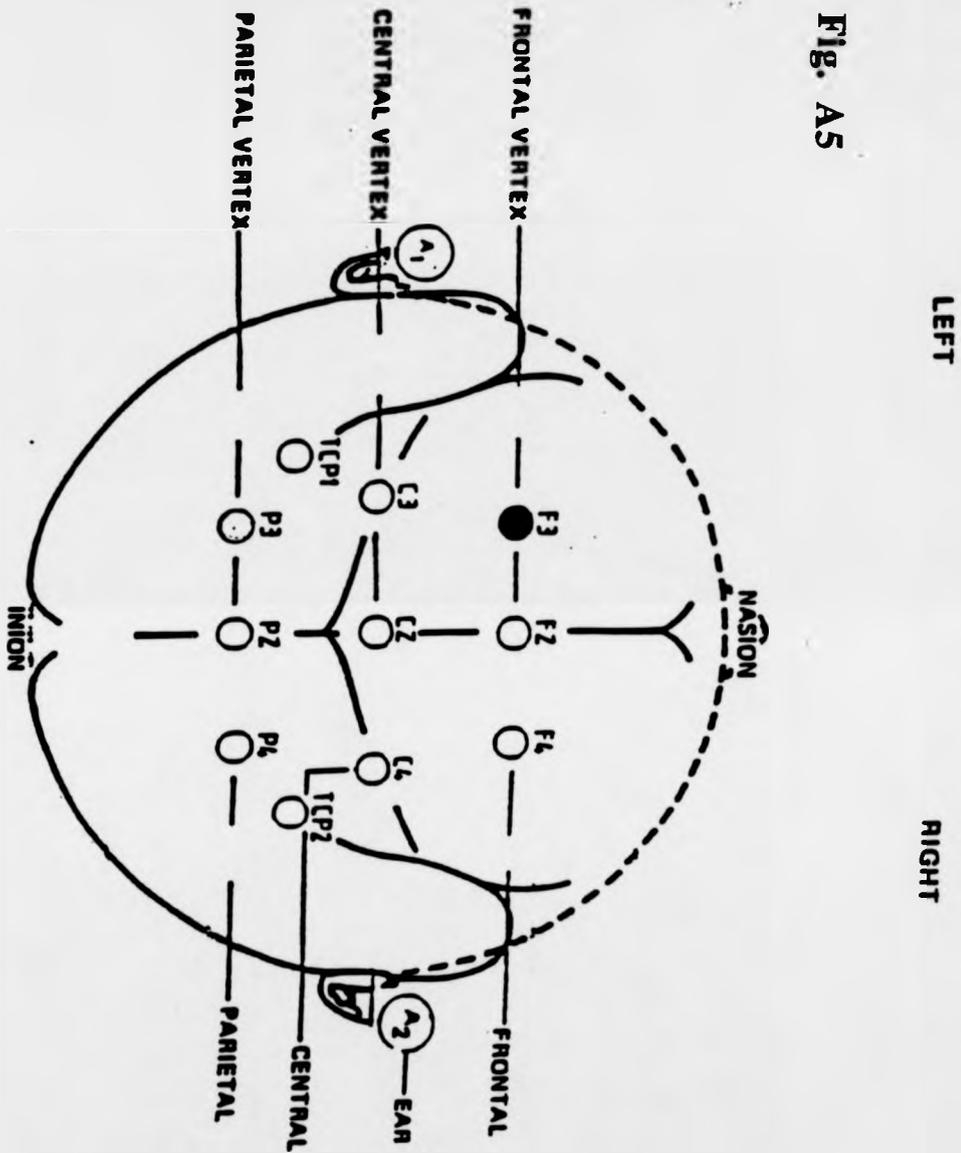
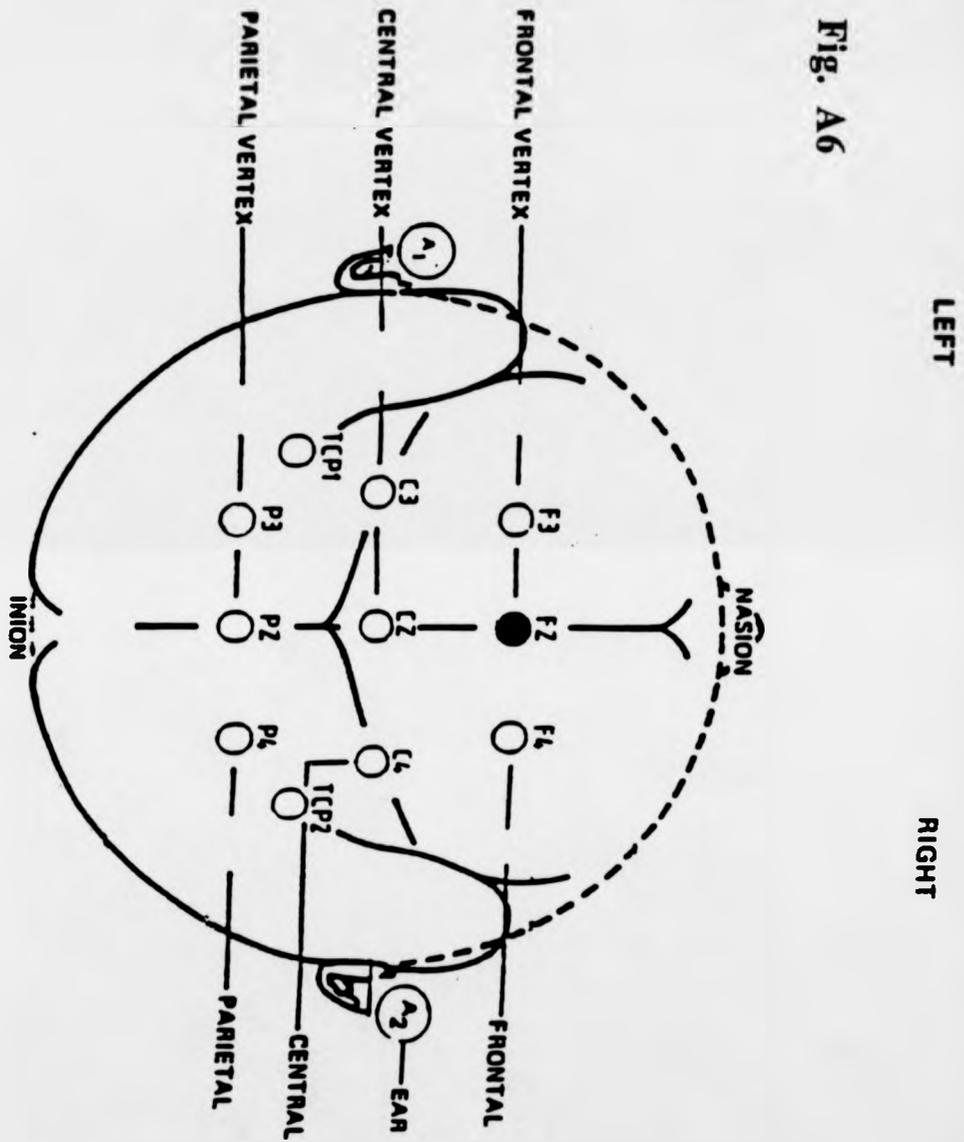


Fig. A6



LEFT

RIGHT

Fig. A7

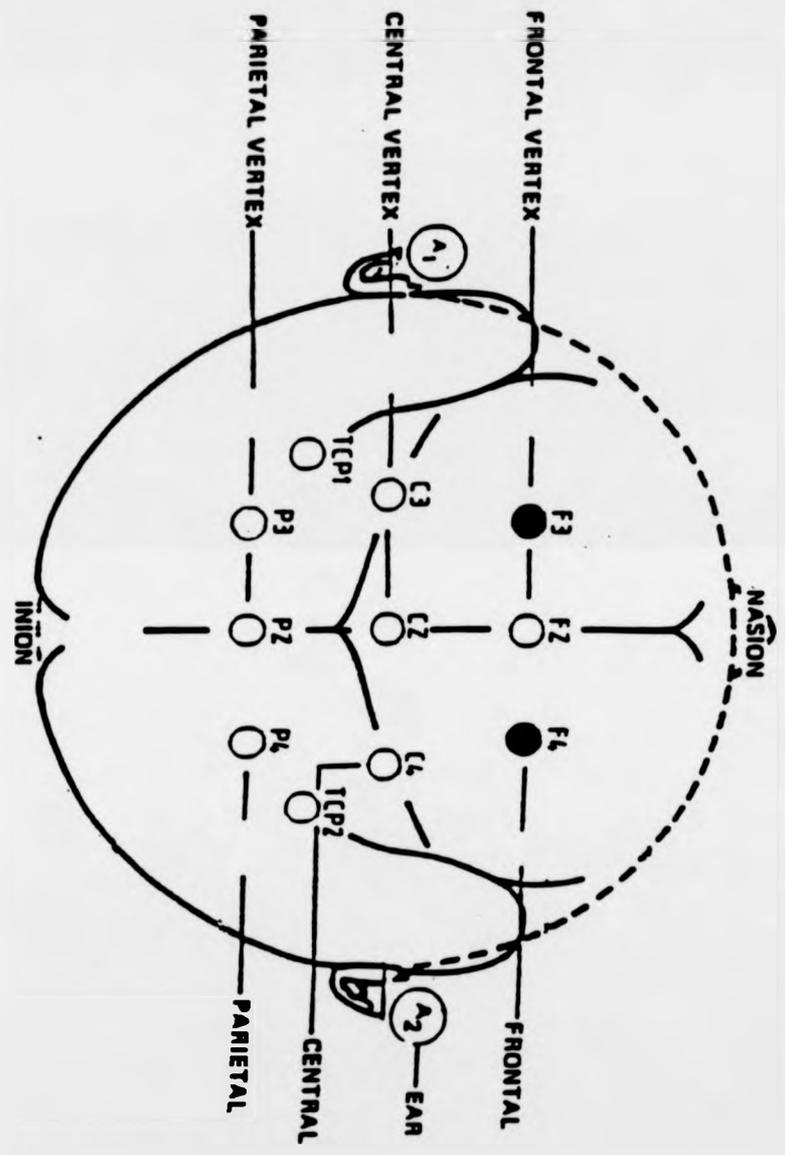




Fig. A9

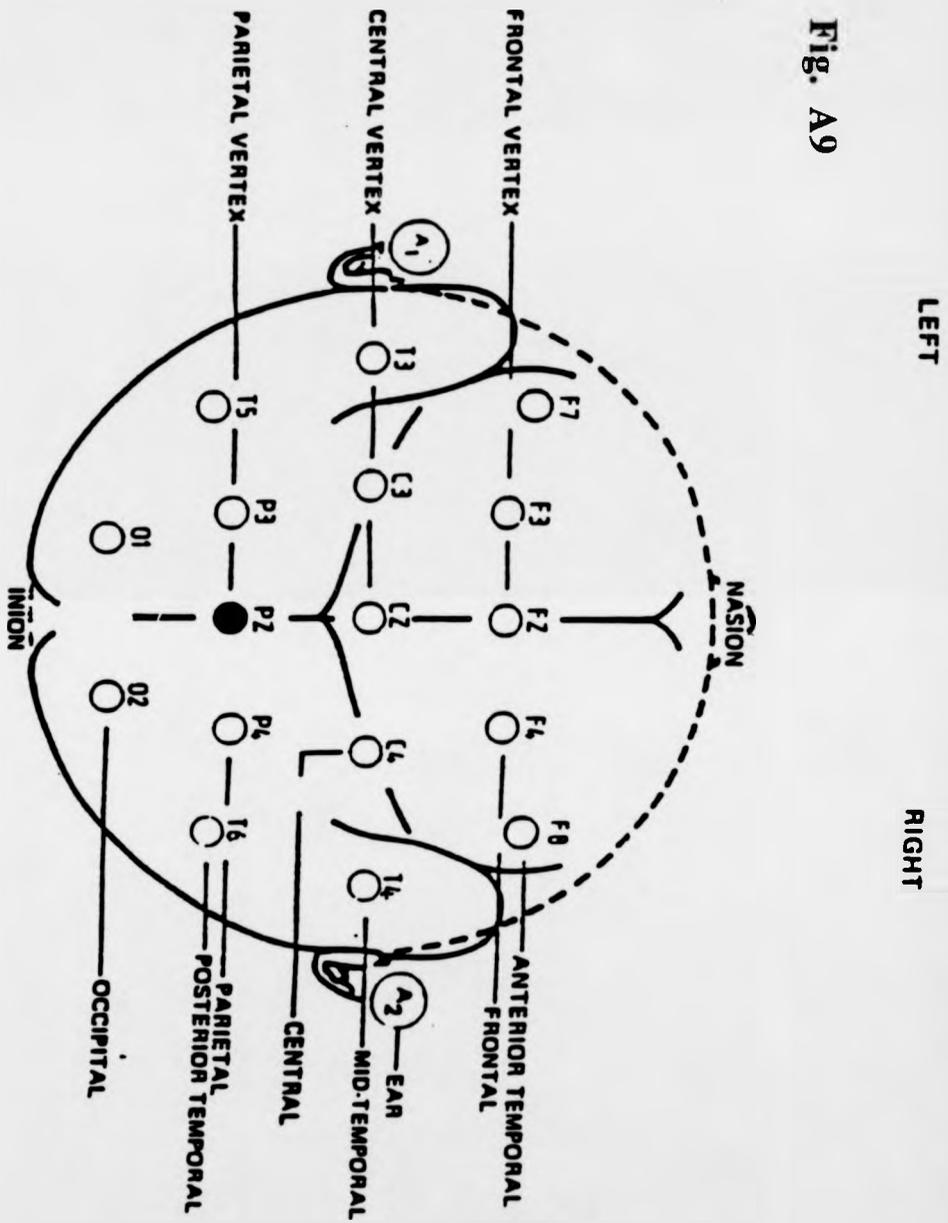


Fig. A10

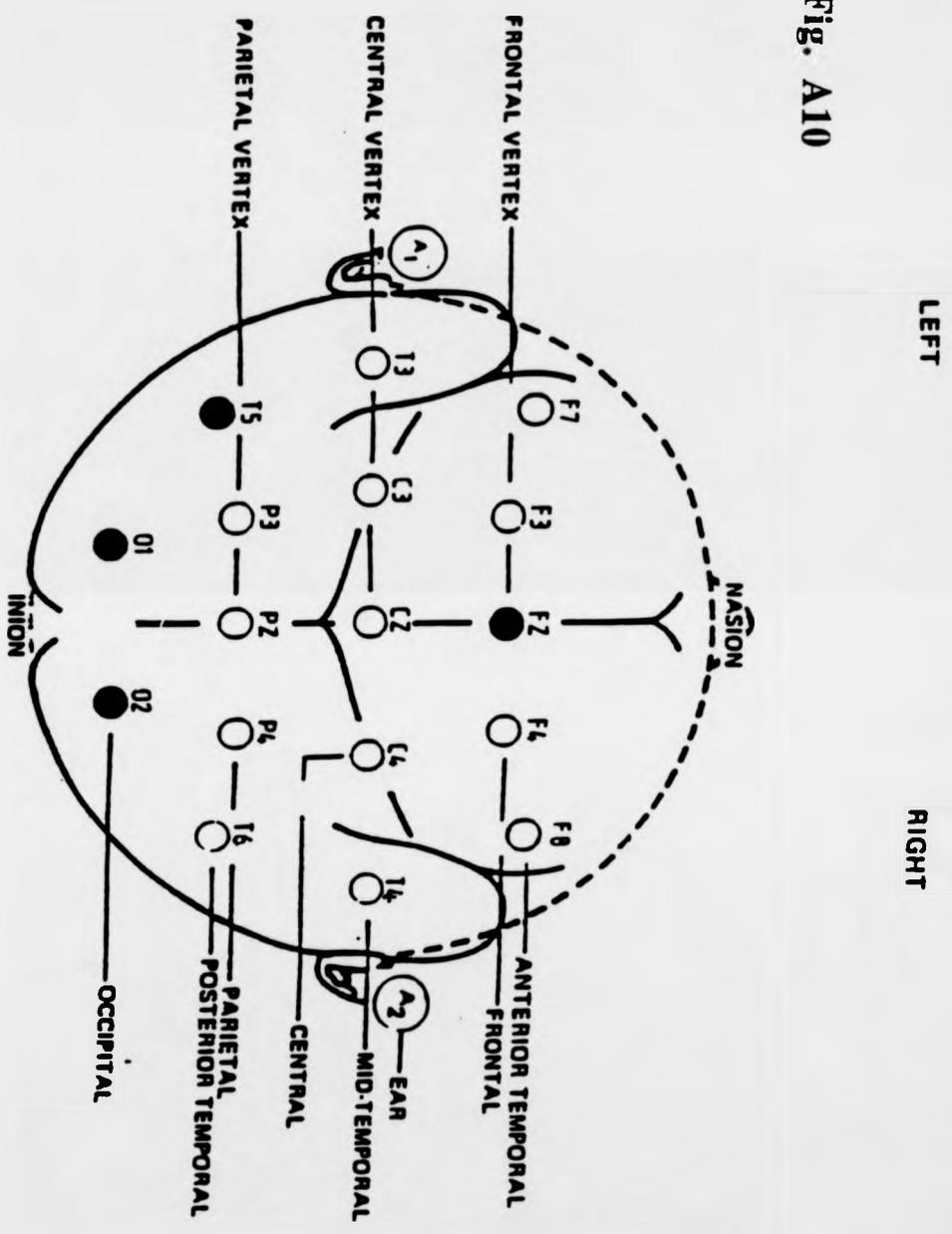
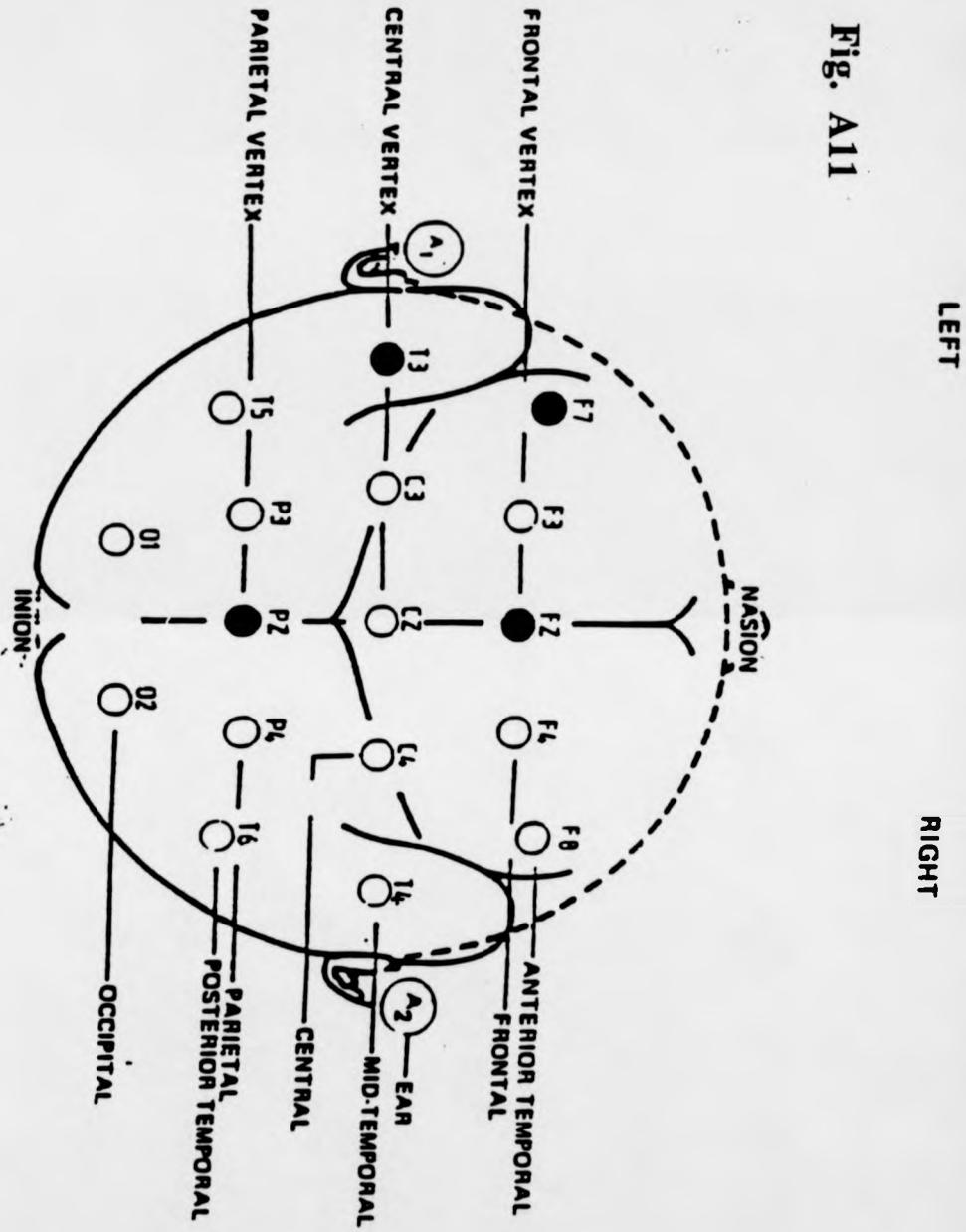


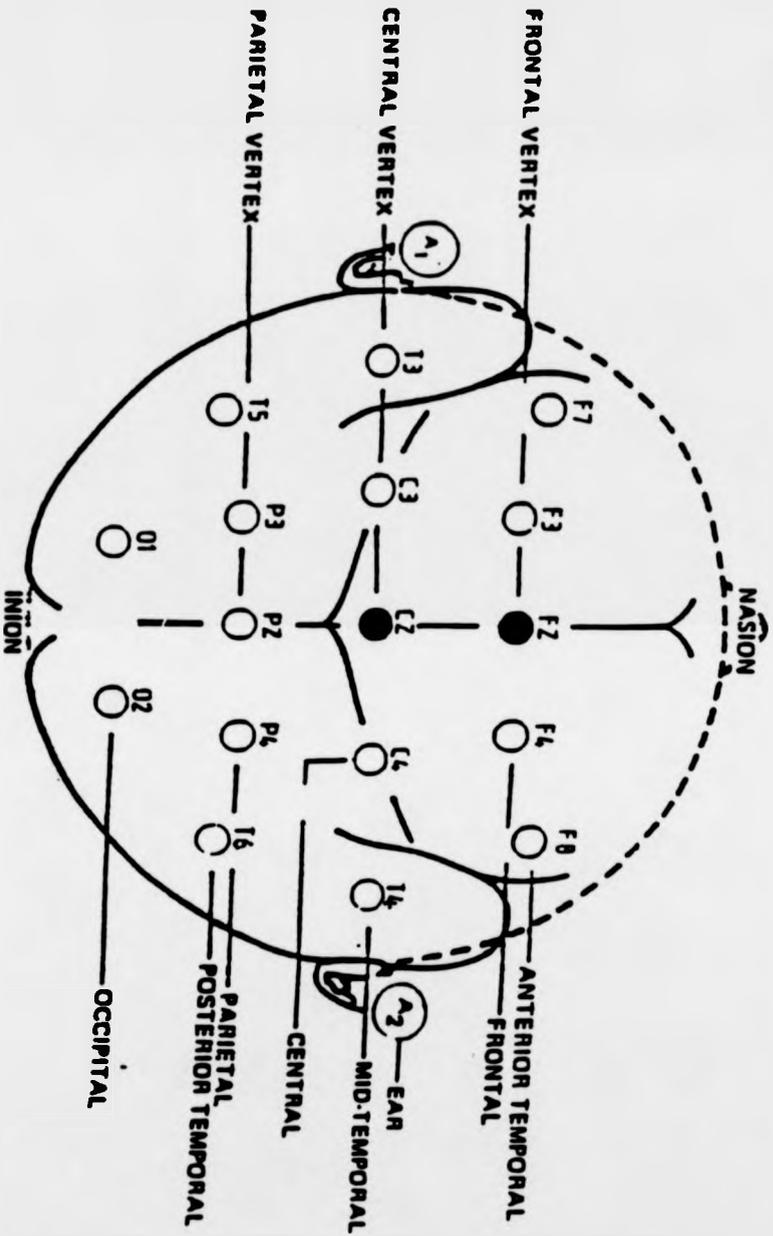
Fig. A11



LEFT

RIGHT

Fig. A12



## **~APPENDIX B~**

### **Testing materials**

- B1. Handedness questionnaire.**
- B2. Psychometric odour rating sheets for experiment 1.**
- B3. Psychometric rating sheets for experiment 2.**
- B4. Psychometric odour rating sheets for experiment 3.**
- B5. Odour discrimination test.**

**B1: Handedness questionnaire**

## Handedness Questionnaire

Name..... Age..... Sex.....

Are any of your immediate relatives left-handed?.....

If so, please indicate their relationship to you (eg.

mother, father, sister).....

Please indicate your preferences in the use of the hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. In any case where you are really indifferent, put + in both columns.

Which hand do you use :-

	LEFT	RIGHT
1. To write a letter?		
2. To throw a ball at a target?		
3. To hold a tennis racket?		
4. To hold a match whilst striking it?		
5. To cut with scissors?		
6. To guide a thread through the eye of a needle?		
7. At the top of a broom when sweeping?		
8. At the top of a shovel when digging?		
9. To deal playing cards?		
10. To hammer a nail into wood?		
11. To hold a toothbrush when using it?		
12. To unscrew the lid of a jar?		

**B2: Psychometric odour rating sheets for  
experiment one**

ODOUR RATING SCALES

Rate the odour on the following scales by marking  
a cross or a hatch mark on the scale at the point  
which corresponds to your judgement.

UNFAMILIAR ————— FAMILIAR

WEAK ————— STRONG

UNPLEASANT ————— PLEASANT

ODOUR RATING SCALES

Rate the odour on the following scales by marking  
a cross or a hatch mark on the scale at the point  
which corresponds to your judgement.

PLEASANT \_\_\_\_\_ UNPLEASANT

STRONG \_\_\_\_\_ WEAK

FAMILIAR \_\_\_\_\_ UNFAMILIAR

**B3: Psychometric odour rating sheets for  
experiment two**

Please place a mark at that point along the line  
which corresponds to your judgement.

ODOUR.....

PLEASANT

NOT AT ALL  
PLEASANT



WEAK

STRONG



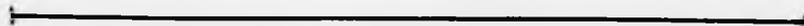
UNFAMILIAR

FAMILIAR



STINGING

SOOTHING



ALERTING

RELAXING



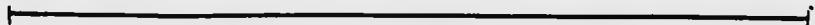
NOT AT ALL  
SWEET

SWEET



NOT AT ALL  
SAVOURY

SAVOURY



Please place a mark at that point along the line according to your judgement.

ODOUR.....

NOT AT ALL  
PLEASANT

PLEASANT



STRONG

WEAK



FAMILIAR

UNFAMILIAR



SOOTHING

STINGING



RELAXING

ALERTING



SWEET

NOT AT ALL  
SWEET



SAVOURY

NOT AT ALL  
SAVOURY



**B4: Psychometric odour rating sheets for  
experiment three**

# ODOUR RATINGS

PLEASE RATE THE ODOUR ON THE FOLLOWING DIMENSIONS. PLACE A MARK AT THAT POINT WHICH YOU THINK CORRESPONDS TO YOUR JUDGEMENT. TRY AND WORK THROUGH THE ODOURS AS QUICKLY AS POSSIBLE.

PLEASANT

NOT AT ALL  
PLEASANT

\_\_\_\_\_

WEAK

STRONG

\_\_\_\_\_

FAMILIAR

NOT AT ALL  
FAMILIAR

\_\_\_\_\_

ALERTING

CALMING

\_\_\_\_\_

MAKES ME HAPPY

DOES NOT MAKE  
ME HAPPY

\_\_\_\_\_

MAKES ME  
HUNGRY

DOES NOT MAKE  
ME HUNGRY

\_\_\_\_\_

WHAT IS THE NAME OF THE ODOUR?      ODOUR CODE:

.....

.....

WOULD YOU, ON ANY OCCASION, EAT (OR DRINK) THE FOOD  
EMITTING THIS AROMA?

YES/NO

# ODOUR RATINGS

PLEASE RATE THE ODOUR ON THE FOLLOWING DIMENSIONS. PLACE A MARK AT THAT POINT WHICH YOU THINK CORRESPONDS TO YOUR JUDGEMENT. TRY AND WORK THROUGH THE ODOURS AS QUICKLY AS POSSIBLE.

NOT AT ALL  
PLEASANT

PLEASANT

---

STRONG

WEAK

---

NOT AT ALL  
FAMILIAR

FAMILIAR

---

CALMING

ALERTING

---

DOES NOT MAKE  
ME HAPPY

MAKES ME  
HAPPY

---

DOES NOT MAKE  
ME HUNGRY

MAKES ME  
HUNGRY

---

WHAT IS THE NAME OF THE ODOUR?

ODOUR CODE:

.....

.....

WOULD YOU, ON ANY OCCASION, EAT (OR DRINK) THE FOOD  
EMITTING THIS AROMA?

YES/NO

**HOW HUNGRY ARE YOU?**

**VERY HUNGRY**

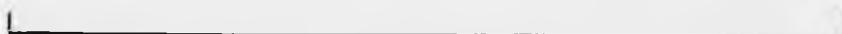
**NOT AT ALL HUNGRY**



**HOW FULL ARE YOU?**

**VERY FULL**

**NOT AT ALL FULL**



**HOW HUNGRY ARE YOU?**

NOT AT ALL HUNGRY

VERY HUNGRY



**HOW FULL ARE YOU?**

NOT AT ALL FULL

VERY FULL



**B5: Odour discrimination test**

### Odour discrimination test

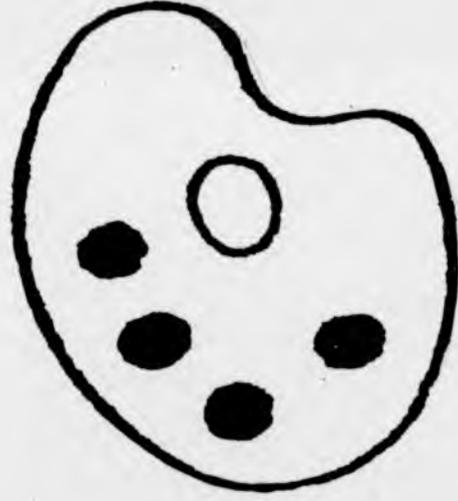
The discrimination test was a simple, forced-choice task requiring subjects to discriminate three odorants from a blank, no-odour control. The odorants were banana (2 microlitres, 10% in DEP, supplied by PPF), peach (2 microlitres, H&R) and eucalyptus (2 microlitres of eucalyptus oil, H&R) and were presented on perfumers' strips kept in test tube bottles. The no-odour control was a perfumer's strip untainted by any odorant. Subjects were instructed to sniff each strip for as long as required and, after all strips had been sampled, were required to give their judgement. Those subjects able to distinguish between the no-odour control and the odorants were allowed to participate in the EEG experiments.

## **~APPENDIX C~**

### **EEG recording equipment**

- C1. The NeuroscienceBrain Imager Series III model.**
- C2. Waveform decomposition.**
- C3. Experimental conditions.**
- C4. Materials.**

# NUMEROUS ORIGINALS IN COLOUR

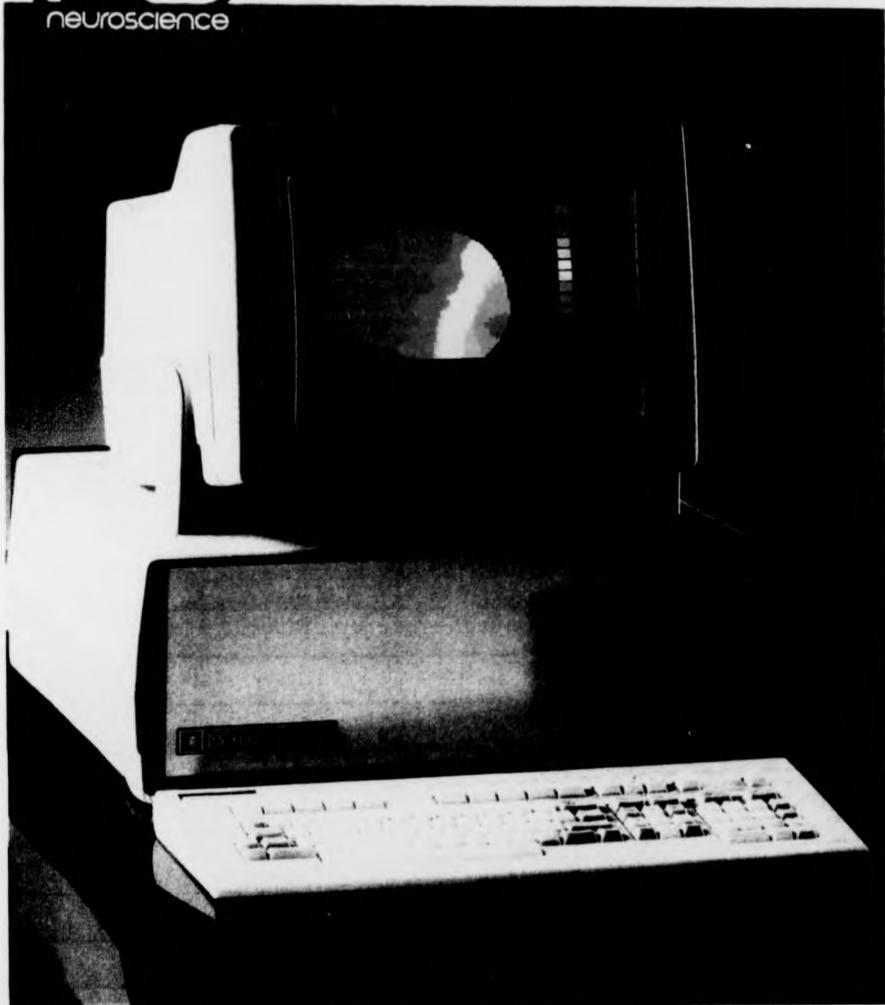


**C1: Neuroscience Brain Imager series III model**



neuroscience

# BRAIN IMAGER



The Neuroscience Brain Imager series III model records real-time EEG from 28 channels in five frequencies: delta (1-4Hz), theta (4-8Hz), alpha (8-13Hz), beta 1 (14-22Hz) and beta 2 (22-30Hz). The 28 electrodes are attached to an elastic cap, to allow flexibility in covering the subject's scalp, and are arranged according to the 10/20 International Placement System. The imaging system may be used to record real-time EEG or time/event-locked EEG (ERPs). The mapping system allows the relative shifts in frequency activity to be monitored via coloured topographical representations of EEG activity. These colours represent amplitude within a specific frequency. A Fast-Fourier Transform algorithm analyses and separates the raw EEG waveform into the five classical frequencies (as illustrated in **Appendix C2**). The Imager acquires an average of 2.56 seconds of activity (epochs or frames) and converts the activity into a coloured topographical map (as described in **section 6.6. of Chapter 6**). The voltage from each active electrode is compared with a less active reference (in the experiments described in **Chapters 5-7**, linked earlobes were used as references. There continues to be controversy over the most ideal site for the location of reference electrodes (see, e.g., Davidson, 1988; Kahn *et al*, 1988) since most sites of the body are electrically active (Nunez, 1981). Linked ears, however, have proved to be one of the more effective noncephalic references since a common reference is provided for electrodes on both sides of the scalp. It should be noted, however, that no comprehensive study has explored the relative effectiveness of the various available electrode reference sites).

The resulting image is a conceptually simple representation of the EEG's scalp-activity enabling the "clinician to more easily localise the site of any abnormality" (Neuroscience promotional material). This ability to give simple indicators of gross brain pathology is one of the primary advantages of the mapping system. However, for the analysis of more subtle and visually inconspicuous changes in EEG topography

or amplitude, numerical values (amplitude in microvolts) may be obtained on hardcopy or transferred to an alternative computer store (via its RS-232 port) where more complex statistical analysis may take place. The Imager has the facility for simple statistical analysis such as t-tests and is able to create group averages create normative data. For complex analysis, however, the data are most appropriately analysed using a statistical package. In the present thesis, SYSTAT Inc. statistical software was used to analyse the data, off-line.

Storage of the EEG recording may be made on floppy (magnetic) or optical (non-magnetic) disk. The advantage of the optical disk is that data are recorded onto a disk via laser thus ensuring a greater degree of disk security than normal magnetic disks. Data (including both EEG waves and brain maps) may be stored in this way and can not be deleted. However, storage of Evoked Potential data may be made only on non-optical disks. Magnetic disks may also store the brain maps but not the EEG waveforms.

## **C2: Waveform decomposition**

# The Formation of Topographic Maps From EEG Waveforms

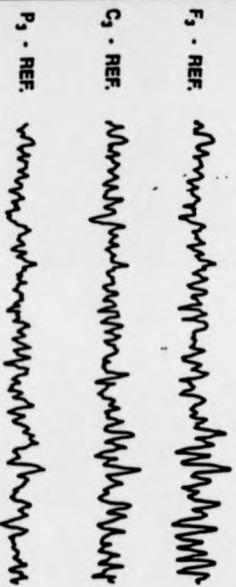


FIGURE 1. EEG waveforms are a very complex summation of many frequencies.

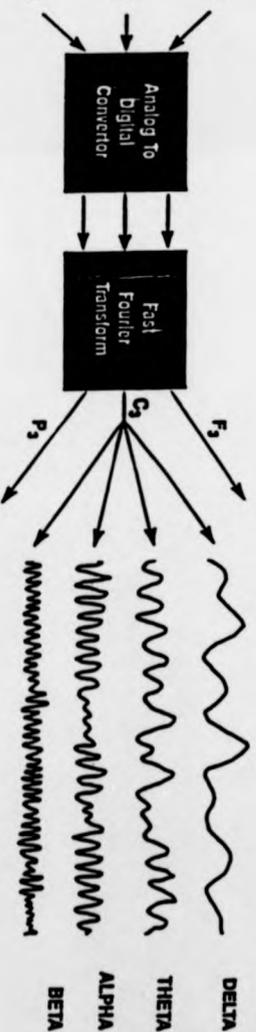


FIGURE 2. The EEG waveforms are digitized and divided into 2.5 sec epochs.

FIGURE 3. Each epoch for each channel of EEG is analyzed with the Fast Fourier Transform (FFT) algorithm to separate the complex EEG into its simpler waveform components.

**C3: Testing conditions:**

- (i) Subject in low odour room**
- (ii) Odour presentation**
- (iii) Debriefing**

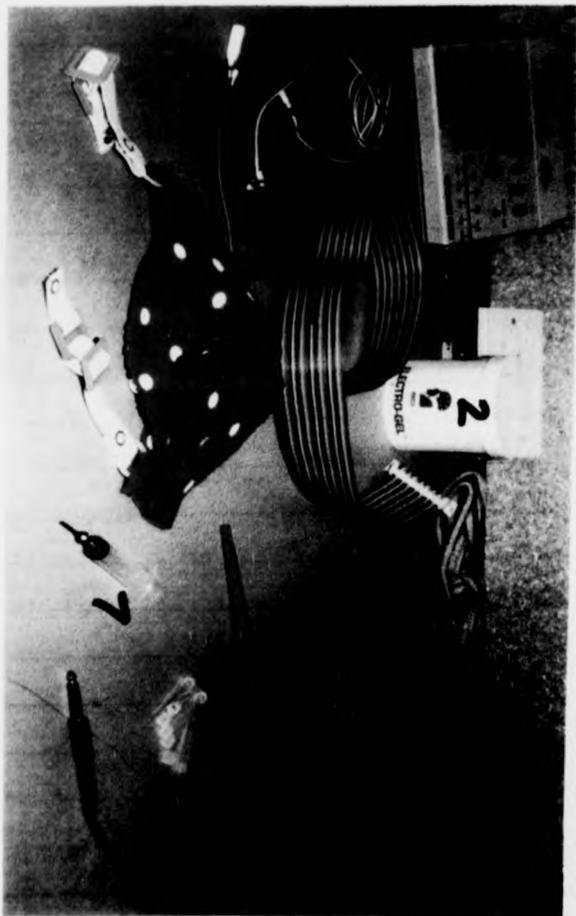






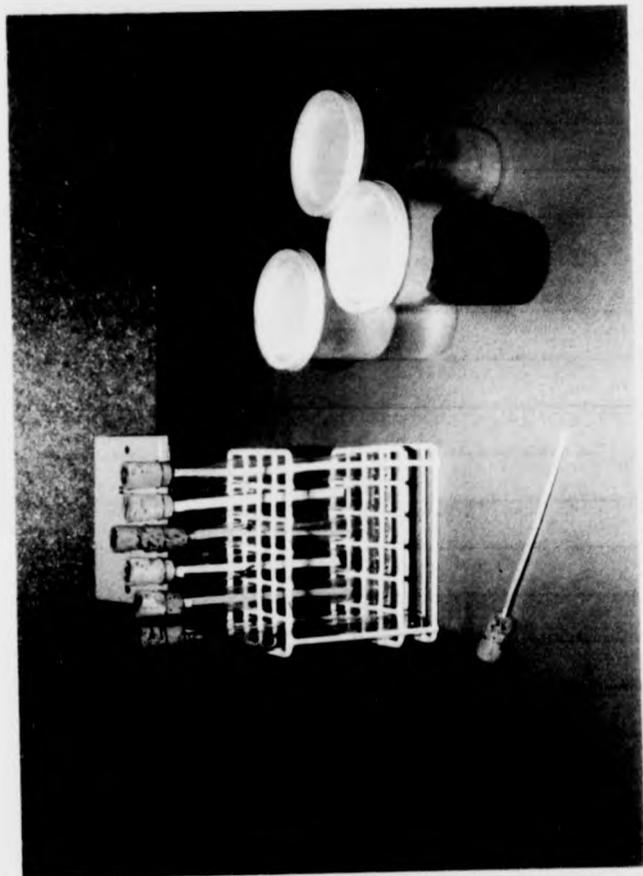
#### **C4: Materials**

- (i) Imager and electrode equipment**
- (ii) Olfactory testing materials**



## **Appendix C4 (i) key**

1. Impedance meter.
2. Electro-gel.
3. Chest band for attaching electrode cap chin straps.
4. Headphones.
5. Occluded goggles.
6. Pipette and pipette nibs (used for dispensing odorants).
7. Syringe for the application of electro-gel.
8. Electrode cap with chin straps.
9. Ear reference electrodes.



## **Odour presentation and storage**

Odours were either presented on perfumers' strips (seen in the test tubes in the photograph) or in plastic beakers (also seen). The method of storage and presentation was dictated by type of stimulus material. Simple odorants were presented on the perfumers' strips. Those odorants derived from foodstuffs not available as commercial odorants were presented in odourless plastic beakers. Stimuli kept in beakers were sealed until presented to the subject. These were disposed of at the end of each experimental session. Fresh stimuli were prepared on the morning of each testing session.

**~APPENDIX D~**

**BatchCommander programme**

**(c) G. Milligan  
Department of Psychology  
University of Warwick**

--

```
on OFile
  global OldFile, OText, LoadOK

  if OldText is empty then put "Select file for conversion." into OText
  set lockScreen to true
  put fileName("TEXT", OText) into OldFile
  if OldFile is "Cancel" or OldFile is empty then
    put 0 into LoadOK
    exit OFile
  else
    put 1 into LoadOK
  end if
  set lockScreen to false
  put empty into OText
end OFile
```

```
on SFile
  global NewFile, SText, OldFile, SaveOK
  if SText is empty then put "Name of new File" into SText
  set lockScreen to true
  get NewFileName (stext, "Master Command File")
  if it is empty or it is "Cancel" or it contains " _f ¢ ` ¶ " then
    put 0 into SaveOK
    exit SFile
  else
    put 1 into SaveOK
  end if
  put it into NewFile
  set lockScreen to false
end SFile
```

```
on OpenStack
  global fileOK, CommandOk
  hide menubar
  put 0 into cd fld "totalfile"
  put 0 into fileOK
  put 0 into CommandOk
  put empty into cd fld "DataFileDisplay"
  put empty into cd fld "CommandDataDisplay"
end OpenStack
```

```
on CloseStack
  put 0 into cd fld "totalfile"
```

```
put 0 into fileOK
put 0 into CommandOk
put empty into cd fld "DataFileDisplay"
put empty into cd fld "CommandDataDisplay"
put the UserLevel into user
set the UserLevel to 5
DoMenu "Compact Stack"
set the UserLevel to user
end CloseStack--
-- 1 BackGgrounds
--
-- BackGground 1
--
--
-- number of BackGround Fields 0
--
-- number of BackGround buttons 0
--
-- Foreground CARD 1
--
--
-- number of Card Fields 7
--
-- script of card field "DataFileDisplay" (# 1 )
--
-- script of card field "CommandDataDisplay" (# 2 )
on MouseClick
  global CommandData
  put cd fld "CommandDataDisplay" into CommandData
end MouseClick--
-- script of card field id 7 (# 3 )
--
-- script of card field id 8 (# 4 )
--
-- script of card field id 9 (# 5 )
--
-- script of card field id 13 (# 6 )
--
-- script of card field "totalfile" (# 7 )
--
-- number of Card Buttons 6
--
-- script of card button "Select Data Files" (# 1 )
on mouseUp
  global fileList, fileOk, LoadOK, OldFile
```

```

    put FullSFPack(M,BINA,,, "Select required systat data files") into
dump

-- CHECK FOR CANCEL
if dump is empty then exit mouseUp

-- CHECK FOR ERRORS
if dump = "Error : FullSFPack needs System 7.0" then

-- I EXPECT WE ARE RUNNING SYSTEM 6 RUNNING SYSTEM 6
answer file "Select text list of systat files to import"
if it is empty then exit MouseUp
put it into OldFile
put 1 into LoadOK

-- put "Select list of files to import" into OText
-- OFile
-- if LoadOK <> 1 then exit mouseUp
-- put OldFile into filename

-- GET LIST OF FILENAMES
open file OldFile
put empty into dump
repeat
    read from file OldFile for 16384
    if it is empty then exit repeat
    put it after dump
end repeat
close file OldFile

else
if dump = "Error : Missing or empty parameter" or —
dump = "Error : Bad action parameter" then
    beep
    answer dump & ". Contact Greg Milligan for advice (EMail:
psafj@csv.warwick.ac.uk)." with "Ok"
    put 0 into fileOk
    exit mouseUp
end if
end if

-- INFO LOOKS OK
put dump into fileList

```

```
put fileList into cd fld DataFileDisplay
if fileList is empty then
  put 0 into fileOk
  put "0" into cd fld "totalfile"
else
  put 1 into fileOk
  put the number of lines of fileList into temp
  put temp into cd fld "totalfile"
end if
end mouseUp--
-- script of card button "Select Cmd Template" (# 2 )
on mouseUp
  global OldFile, OText, CommandData, CommandOK, LoadOK

  put "Select command file" into OText

  OFile
  -- CHECK FOR CANCEL

  if LoadOK = 0 then
    beep
    exit mouseUp
  end if

  put empty into CommandData
  put empty into cd fld "CommandDataDisplay"

  open file OldFile
  repeat
    read from file OldFile for 16384
    if it is empty then exit repeat
    put it after CommandData
  end repeat
  close file OldFile

  put CommandData into cd fld "CommandDataDisplay"
  if CommandData is empty then
    put 0 into CommandOk
  else
    put 1 into CommandOK
  end if
end mouseUp--
-- script of card button "Generate Command File" (# 3 )
on mouseUp
```

global fileOk, CommandOk, SaveOK, LoadOK  
global NewFile,SText,OldFile, CommandData, fileList

-- UPDATE COMMAND DATA FROM EDITORS WINDOW

put cd fld "CommandDataDisplay" into CommandData

if CommandData is empty then

put 0 into CommandOk

else

put 1 into CommandOk

end if

-- ARE WE READY TO GENERATE COMMAND FILE

if fileOk <> 1 then

beep

answer "Please select at least one data file to work with via the  
'Select Data Files' button." with "Ok"

exit to hypercard

end if

if CommandOk <> 1 then

beep

answer "Either select a command template to work with, or type  
the routine in the command editor window below." with "Ok"

exit to hypercard

end if

-- RESET VARIABLES

put 1 into linecounter

put 1 into charcounter

put 1 into filecounter

put the number of lines in fileList into maxfile

put the number of characters in CommandData into maxchar

-- INSURE THAT THE ROUTINE IS TERMINATED WITH A <CR>

if character maxchar in CommandData <> return then

put return after CommandData

add 1 to maxchar

end if

-- ASK USER FOR NAME OF MAC GENERATED COMMAND FILE

put "Name new command file" into SText

SFile

if SaveOK = 0 then

```
beep
exit MouseUp
exit to HyperCard
end if
```

```
open file NewFile
set cursor to busy
Write "SYSTAT" && return to file NewFile
```

```
-- START CREATING COMMAND FILE
repeat for maxfile
```

```
set cursor to busy
put 1 into charcounter
put line filecounter of fileList into OldFileName
```

```
-- CHECK TO SEE IF WE HAVE ENOUGH CHARACTORS TO ADD A
SUFFIX
```

```
put OldFileName into dump1
```

```
-- SCAN BACKWARDS FOR COLON (USED IN FULL PATH NAMES)
```

```
if dump1 contains colon then
```

```
put empty into dump2
```

```
put the number of characters of dump1 into backcounter
```

```
-- SEARCH FOR START OF REAL FILE NAME FROM FULL PATH NAME
```

```
repeat for (the number of characters of dump1)
```

```
if char backcounter of dump1 is ":" then exit repeat
```

```
put char backcounter of dump1 before dump2
```

```
add -1 to backcounter
```

```
end repeat
```

```
-- FOUND START OF FILE NAME AND APPEND THIS TO NEW FILE
```

```
NAME
```

```
put 1 into forwardcounter
```

```
put empty into dump3
```

```
repeat for backcounter
```

```
put char forwardcounter of dump1 after dump3
```

```
add 1 to forwardcounter
```

```
end repeat
```

```
-- CHECK REAL FILENAME FOR GREATER THAN 26 CHARS IN NAME
```

```
if the number of characters of dump2 > 26 then
```

```

    put 1 into counter
    repeat for 26
      put char counter of dump2 after dump3
    end repeat
    put dump3 into dump1
  end if

end if

-- CREATE SAVE FILENAME WITH SUFFIX
put dump1 & ".Covt" into NewFileName

-- START READING COMMAND DATA
repeat for maxchar

  set cursor to busy
  if char charcounter of CommandData <> "@" then
    put char charcounter of CommandData into temp
    write temp to file NewFile
    add 1 to charcounter
  else

    -- SCAN FOR SPECIAL INSTRUCTION
    put 0 into offset
    put empty into junk

    repeat
      set cursor to busy
      if char (charcounter + offset) of CommandData = " " then exit
    repeat
      if char (charcounter + offset) of CommandData = return then
    exit repeat
      if char (charcounter + offset) of CommandData = linefeed then
    exit repeat
      put char (charcounter + offset) of CommandData after junk
      add 1 to offset
    end repeat

    -- CONVERT OLD FILE NAME
    if junk = "@IMPORTFILENAME" then
      write quote & OldFileName & quote to file NewFile
      add offset to charcounter
      set cursor to busy
    end if

```

```
-- CONVERT NEW FILE NAME
if junk = "@EXPORTFILENAME" then
  write quote & NewFileName & quote to file NewFile
  add offset to charcounter
  set cursor to busy
end if
```

```
-- ADD <CR>
if char charcounter of CommandData = return then
  write return to file NewFile
  add 1 to charcounter
  set cursor to busy
end if
```

```
if char charcounter of CommandData = linefeed then
  write return to file NewFile
  add 1 to charcounter
  set cursor to busy
end if
```

```
--
```

-----

LABELS

```
-- HEY GUYS THIS IS WHERE YOU CAN INSTALL NEW COMMANDS /
-- INTO BATCH COMMANDER.
```

```
--
-- FOR EXAMPLE
-- TO SET A VARIABLE 'SUBJ' IN EACH DATA FILE.
```

```
--
-- if junk = "@SUBJ" then
--   write quote & "LET SUBJ = " & SUBJECTNAME & quote &
return to file NewFile
--   add offset to charcounter
--   set cursor to busy
-- end if
```

```
--
-- OF COURSE YOU WILL NEED TO IMPORT THE SUBJECT NAME AND
-- STORE IT IN THE VARIABLE 'SUBJECTNAME'.
```

```
--
-- HEY.....WHAT DO YOU WANT BLOOD ? HAHA.....
```

```
--
-- PS CHECK OUT OFILE AND SFILE SCRIPTS AT STACK LEVEL
```

-----

```
-- STANDBY DUMB IDEA FOLLOWS.....
--
-- HEY YOU COULD EVEN PROGRAM HYPERCARD TO BUILD A
COMMAND FILE
-- AND LAUNCH SYSTAT WITH THE COMPLETED COMMAND FILE.
HOPEFULLY ?
-- (SUBMITTING IS NOT THE SAME AS OPENING !)
--
-- WHEN SYSTAT FINISHES, COMMAND FILE INSTRUCTS SYSTAT TO
QUIT,
-- CONTROL RETURNS TO HYPERCARD, THEN HYPERCARD USES A
SHUTDOWN XCMD WHEN QUITTING
-- TO SWITCH MAC OFF. AND THERE YOU HAVE IT MIDNIGHT
BATCH PROCESSING !
--
--
--
```

-----

```
end if
end repeat

-- RESET FOR NEXT DATA FILE
set cursor to busy
add 1 to filecounter
put 1 into charcounter
write return & return to file NewFile
end repeat

-- TIDY UP AND GO HOME
if hilite of cd btn id 16 is true then
write "QUIT" & return to file NewFile
end if

close file NewFile
set cursor to hand
beep
end mouseUp--
-- script of card button "Quit" (# 4 )
on mouseUp
DoMenu "Quit HyperCard"
end mouseUp--
-- script of card button "On-Line Help" (# 5 )
on mouseUp
```

```
    go cd "Help"  
  end mouseUp--  
  -- script of card button "Quit Systat After running command file" (# 6  
)  
  --  
  -- Foreground CARD 2  
  --  
  --  
  -- number of Card Fields 2  
  --  
  -- script of card field id 3 (# 1 )  
  --  
  -- script of card field id 5 (# 2 )  
  --  
  -- number of Card Buttons 1  
  --  
  -- script of card button "Return" (# 1 )  
  on mouseUp  
    go cd "Main"  
  end mouseUp--
```

**~APPENDIX E~**

**Semiochemistry and human behaviour**

*The behavioural effects of semiochemicals in humans: an overview.*

Various studies have postulated a role for epidermally secreted semiochemicals and scents emitted by the sex glands in facilitating communication (and especially sexual communication) in human species (Kloek, 1961; McClintock, 1971; Comfort, 1974; Berliner, Jennings-White and Lavker, 1991). The primary candidate for this human "pheromone" has been the steroid androstenone (and its alcohol form, androstenol), a pig-pheromone which incites lordosis in sows thus enabling the insemination of the animal (Melrose, Reed and Petersen, 1971; see Vandenberg, 1983 for review). The findings from human studies, however, are highly inconclusive. Kirk-Smith, Booth, Carroll and Davies (1978) report that both men and women rated photographs of women as sexier and more attractive in the presence of androstenol than did those in a control group, concluding that this finding was "the first clear characterization of an effect of a naturally secreted pure odour on measurements of sexual relationships among human subjects." Other similar but idiosyncratic effects have also been found (Kirk-Smith and Booth, 1980; Cowley, Johnstone and Brooksbank, 1977; Cowley, Harvey, Johnstone and Brooksbank, 1980; Filsinger, Braun, Monte and Linder, 1984; Filsinger, Braun and Monte, 1986; Cowley and Brooksbank, 1991). Morris and Udry (1978), Black and Biron (1982), Benton (1982) and Gustavson, Damon and Bonnett (1987), however, report negative findings. The majority of these experiments tend to expose subjects to volatile chemicals in contexts which are not generally appropriate using measures which are not designed to enhance ecological validity (cf. Kirk-Smith and Booth, 1980; Cowley *et al* 1977; 1979). For example, subjects have rated imaginary verbal descriptions of people (Cowley *et al*, 1979; Filsinger *et al*, 1984), pictures and slides of buildings, people and animals (Kirk-Smith and Booth, 1977; Kirk-Smith *et al*, 1978), worn masks impregnated with an odour (Cowley *et al*, 1980) or a necklace with the odour (Cowley and Brooksbank, 1991), worn the odour on the top lip (Benton, 1982), chosen to sit on a chair (Kirk-Smith and Booth, 1980),

used a doctored changing room cubicle (Gustavson *et al.*, 1987) or indicated the number of sexual partners they have recently had (Filsinger and Monte, 1986). Black and Biron (1982), who required subjects to interact with a confederate of the opposite sex who wore either androstenone or exaltolide reported no effect of these chemicals on the rated attractiveness of the confederate.

The methodological limitations of these studies are considerable and obvious. Investigations have used same sex subjects, used no additional experimental odours and failed to take into account whether the odour was detected by subjects. If one were to support the hypothesis that social and sexual behaviour may be altered or precipitated by the presence of androstenone, the context in which testing takes place would have to have some degree of ecological validity. The odour would, therefore, need to be ambient and/or emitted by the individual. Individuals in the experiments would also need to interact. Black and Biron, whose study fulfilled these criteria, demonstrated no effect of semiochemistry on behaviour. This finding is not altogether surprising. As Filsinger *et al.* (1986) argue, it is not merely olfactory stimulation which may affect 'sexual' behaviour but a panoply of sensory stimulators (visual, auditory, tactile and even gustatory) any of which may have additive or synergistic effects. Thus some combination of visual and olfactory stimulation may be needed in order to elicit a pheromonal response. The odour may not, therefore, in this context, be described as "pheromonal" since it does not of itself elicit a stereotypical behavioural response. It thus appears unlikely that semiochemical odours influence sexual behaviour and affective judgements in a replicable and context-appropriate fashion (Hassett, 1978; Rogel, 1979; Doty, 1981; Filsinger and Fabes, 1985; Schaal and Porter, 1991). As Cain (1978) noted: "Insofar as odor has generally played a part in the initial selection of a mate, it is perfume, rather than body odor, that must take the credit" (p. 203).

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**~APPENDIX F~**

**Olfactory remediation: a critical review**

### ***1. Odour and ill-health: Introduction***

A number of recent popular publications have described the ways in which the perception of specific odours is associated with beneficial effects on health and with the enhancement of well-being (e.g., Valnet, 1980; Tisserand, 1988; Worwood, 1990). Much of this popularisation has been attributed to so-called aromatherapy and its claims to alleviate illness by exposure to odour (in conjunction with other methods) (Martin, 1992; Warren & Warrenburg, 1993). This practice, normally regarded as a fringe interest undertaken by those with little or no scientific or medical training, has received little consideration from the established medical sciences. In view of the lack of experimental rigour which is characteristic of aromatherapy, this neglect is not unexpected. Recent studies in olfactory psychology, however, have focused on the ways in which odour affects aspects of human behaviour such as mood, cognition, memory, person perception and psychophysiology and have suggested a re-appraisal of this unorthodox approach to the mitigation of physical and mental health problems.

It is important at the beginning to distinguish two separate, although not autonomous, areas of activity which co-exist beneath the umbrella of "olfactory remediation". The first is that commonly known as aromatherapy. This area is largely business-driven and does not rely heavily on scientific method. Its practitioners are not normally trained doctors, biochemists or psychologists but are self-trained, interested individuals. The claims made by this area are largely founded on folklore and anecdote. The other area is largely science-driven. Here olfactory stimulation is used as a means of alleviating particular ailments or to induce a particular affective state in a clinical or scientific setting. There are much stricter, tighter controls on the conduct of such a study and these endeavours are not normally considered to be part of aromatherapy but as contributions to psychology or medicine. The former

practice will be discussed in a later section. The latter will concern the remainder of this section.

Studies demonstrating the beneficial effects of odour on illness have been few. Early, intelligent reports were anecdotal. Montaigne (1580), for example, noted that odours caused in him "an alteration in me and work upon my spirits". Watson (1871) suggested the use of aromatic fumes for the treatment of mental disorders. Neither observation, however, precipitated a deluge of experimental research into these idiosyncratic effects. Rovesti (1973), in one of the few and slender reports of its kind, credited bergamot, lime, citrus, jasmine and ylang ylang with alleviating depression but in common with many other studies of the type, it refers primarily to diverting anecdotes and gives no detail of experimentation. Most other early studies reported behaviour-changing effects of olfactory stimulation in frogs, rats and freshly cultivated bacteria (Binz, 1879; Pouchet & Chevalier, 1903; Mayer, 1886; Macht & Ting, 1921; Macht & Kunkel; 1920).

The association between foul odours and ill-health are common. The existence of an association between a "bad" odour and bad health has been illustrated by Cain (1978) who cites the example of unpleasant odours arising from poor sanitary conditions as fostering such an association. Other examples might include the odour of rotting food, which acts as an effective caveat, warning of the potentially fatal danger of ingestion (Hines, 1977-8; Rozin & Vollmecke, 1986). Certain illnesses are also characterised by the emissions of distinctive, obnoxious odours (Liddell, 1976; Mace, Goodman, Centerwall & Chinnock, 1976; Doty, 1981). Phenylketenuria, a metabolic disorder of amino acid metabolism, is associated with a musty, mousy odour; diabetes mellitus is characterised by acetone on the patient's breath; Oasthouse urine disease is associated with yeast-like odour. Cain (1978) suggests that the converse hypothesis -that a strong association exists between pleasant odours and health benefits- is unlikely. There have been examples in which exposure to

odour has been shown to be associated with beneficial alterations in mood (Baron, 1990; Knasko & Gilbert, 1990; for a discussion of the non-health associations between odour and behaviour, see Martin, 1994) although there are a small number of other studies which have shown apparent alleviation of illness or an undesirable behaviour as a result of the administration of odour. These studies, however, have several shortcomings in their methodology and interpretation of results and will be considered below.

Ionasescu (1961), in one case of temporal lobe epilepsy, reported an inhibition of seizures by unpleasant odours or a precipitation by a pleasant one. Gowers (1881) observed that epileptic attacks could sometimes be arrested by a strong olfactory stimulus or by the application of ammonia. Passouant (1965) observed that odours may not only precipitate a seizure but may also prevent it. Efron (1956) reported that in one case of Jacksonian epilepsy, fits could be suppressed by the presentation of hydrogen sulphide and dimercaprol. There was no decrease in the frequency of seizures but depersonalization and the actual seizures ceased. Rood (1959), one of the first therapists to explore the potential of sensory stimulation in therapy, claimed a primitive form of response in a polio patient exposed to vinegar. Fox (1965) found that olfactory stimulation by peppermint oil temporarily improved tactile function in 10 congenitally blind children. Kaada (1951) reported that muscle tone or movement may be inhibited by olfactory stimulation although Schwartz (1979) found that only a small percentage (approximately 10%) of muscle movement records was affected by inhalation of ammonia and peppermint oil. Blood pressure has also been reported to increase in response to irritating odours (Allen, 1929; Yamamoto and Iwana 1961) and Ottoson (1963) reported that olfactory stimulation produced alterations in blood sugar level.

Baumeister and Baumeister (1978) reports that in two retarded young girls who engaged in repetitive self-injurious behaviour, ammonia produced rapid and durable suppression of

violence. A similar result was reported by Tanner and Zeiler (1975) in the treatment of a self-injurious 20 year old autistic female. The effect of the use of chemicals in these later studies is almost certainly, however, the result of stimulation of the trigeminus and not primarily the olfactory nerve.

King (1983, 1988) recently reported a method of anxiety-alleviating therapy which combines traditional relaxation therapy, imagery instructions and the presentation of a scene-appropriate fragrance and claimed that this method may reduce anxious tension. No statistical analysis was provided to support this conclusion and the method was only employed with a small number of highly anxious subjects with no control group. A further complication is that there is difficulty in partialling out the effects of the various components of the therapy. The respective contributions of each element of the therapy is unknown and unquantified. It may not be the odour which alleviates anxiety, therefore, but some other component of the treatment. A second and third experimental group-one employing traditional relaxation therapy and the other an odour only would help establish the relative contribution each component makes to anxiety treatment.

Schiffman and Siebert (1991), drawing on unpublished data, report that a behaviour technique which teaches patients to associate an odour (apricot) with a state of relaxation resulted in self-reports of relaxation when the odour alone was presented. Interestingly, early systematic desensitization studies sometimes employed food odour as the conditioned stimulus. Foreyt and Kennedy (1971) treated overweight patients by pairing unpleasant smells with the patient's favourite food. After nine weeks of conditioning, the experimental group showed a weight loss of over 13 pounds in comparison to 11 pounds for controls. At 48 weeks, the sample had lost 91 pounds whereas the controls had gained 11 pounds. A recent report has suggested similar weight reduction occurring with inhalation of 2-acetylpyridine (Hirsch, 1993). Schiffman (1992) also reports that

alleviation of depressive moods was effected by inhalation of food and fruit odours from bottles and when these odours were pumped surreptitiously into patients' rooms although no details of methodology of statistical analysis are provided.

A similar finding to that of Schiffman and Siebert has been reported by Mann and Redde (1991) who found that patients undergoing a CAT scan in the presence of heliotropin -a vanilla-like scent- reported 63% less overall anxiety than patients exposed to no odour. However, these results are also similarly unpublished and statistical analyses are absent. It would be interesting to discover whether the valence of an odour produces these effects and whether the odour is simply a distraction and not an anxiety-alleviative as such. The odour may not directly reduce anxiety via relaxation, association, direct limbic link or biochemical alteration but may be a fragrant curio which displaces attention from scanning to smelling. It is a strong possibility that the pleasantness of the odour is a potent mediating variable.

## ***2. Aromatherapy.***

Aromatherapy has a long history. The therapeutic use of odour via fumigation has been reported in many ancient civilisations. The ancient Babylonians, 1500 B.C., used the odour of frankincense to exorcise demons (Roebuck, 1988). The use of frankincense to heighten religious experience has been reported for centuries. The odours of various plants and animals are common folkloric elements in warding off demons and illness (Mackenzie, 1886). Medieval attributions for some odours included chronic disease, convulsions, abortion and death (Cain, 1978) whereas the 16th, 17th and 18th centuries saw the use of odorous pomanders and vinaigrettes as stimulants and antiseptics (Roebuck, 1988). The scientific developments of the nineteenth century, however, were critical in establishing that disease was not contracted by volatile particles transmitted via the air but by direct contact (Corbin, 1986).

Aromatherapy was first explicitly described in the 1920s by Gattefosse who suggested the use of essential oils for medicinal purposes (Gattefosse, 1928). Its modern incarnation has been described as "the therapeutic use of volatiles to cure or to mitigate or to prevent diseases, infections and indispositions only by means of inhalation." (Buchbauer, 1990) which, in view of a great deal of modern practice, is a rigid and narrow definition since a number of publications suggest not only the use of inhalation as a means of mitigation but also the use of other "therapies" such as massage, the common concomitant of inhalation (Tisserand, 1988).

A considerable problem associated with these reports is objectivity. Frequently, studies are conducted with no objective measurement, no follow-up and no alternative treatment programmes (including placebo) with which to compare the effects of the experimental variable. One recent study has attempted to establish more objective criteria for the assessment and application of odour by conducting interviews, instructing subjects when and where to inhale the odour (incense) and using a medical index. Its results, however, were highly variable with treatment being highly effective in only 23% of cases (Hasegawa, 1978; cited in Takagi, 1989).

The methodological difficulties in such treatments are obvious. In a review of the practice of aromatherapy, Dodd (1988) presents several strong arguments against many of the claims of its practitioners. Frequently in such sessions there is rarely a follow-up period whereby the effects of the odour can be assessed. When these effects are assessed, they are done on the basis of the aromatherapist's observation. The degree of subjectivity involved in this assessment and the probable influence of "experimenter bias" suggests a less odorous explanation for the apparent effects observed.

Perhaps a more serious criticism is the failure to carry out a proper "medical" trial which would establish the genuine therapeutic effects of stimulation by odour. This would entail not only the follow-up periods undertaken by normal medical trials but also a large sample (most subjects undergoing aromatherapy are individual cases with varied medical and psychological histories), a proper description of the ailment for which a cure is sought, the proper diagnosis of such an ailment and the employment of a placebo, a no-therapy control and alternative experimental conditions.

Another difficulty, as noted above, is that aromatherapy may include not only inhalation but other aspects of therapy as well. This varied package of treatment is not unique and is seen in phobia and anxiety management. It does, however, render the assessment of the respective contributions of each element to the successful mitigation of the problem presented, difficult. In this respect, Dodd (1988) argues that the term aromatherapy is, in fact, a misnomer since the primary form of "treatment" in aromatherapy is massage with essential oil. He suggests the less misleading alternative term "osmotherapy". Some aromatherapists have claimed that therapeutic odour effects are present even without massage. One, for example, attributes increased levels of relaxation and "lessening of depression" to aromatherapy and argues that this result cannot be "explained away by the actual effects of the massage as I ran many test treatments in my Institute with and without the essential oils and this fact is supported by other colleagues that I have trained." (Roebuck, 1988). Whether this author had any objective measurement of the assumed improvement in well-being is unknown. The anecdotal evidence that is presented is a common example of the type of evidence considered valid in aromatherapeutic circles. It would not be acceptable in medical and scientific discourse.

Ignorance of the chemistry of odours is also common. Tisserand (1977), for example, states that "organic structures like essential oils have a structure which only Mother Nature

can put together. They have a life force which can only be found in living things." However, as Dodd (1988) suggests, so long as impurities are absent from the sample used an oil synthesized in a laboratory will be chemically no different from that isolated from a plant. Further confusion and incomprehension arises over the use of the term essential. As oils contain secondary primary metabolites and are not essential for the life of living cells, the use of the term essential is rather inaccurate.

The foregoing argument states that very little scientific credibility can be attributed to an area of endeavour which has assumed the cachet of medical and scientific credibility. However, this is not to argue that odour may not precipitate genuine beneficial effects on mood and well-being. Properly-controlled psychological studies have recently demonstrated significant effects of odour on mood, social behaviour and cognition (Baron, 1980, 1990; Warm, Dember & Parasuraman, 1991; Knasko & Gilbert, 1990; Knasko, 1992)

### 3. Odour and bulimia.

A traditional form of eliminating undesirable behaviour in psychiatric cases- specific paraphilias, certain types of neuroses and even alcoholism- is the employment of a form of classical conditioning whereby a problem behaviour is reduced by repeatedly pairing it with an aversive stimulus. The aversive stimulus (the conditioned stimulus in classical conditioning parlance) is thought to be associated in the patient's mind with the undesirable behaviour. Since the unwanted stimulus is presented only when the problem behaviour occurs, the patient learns that if he or she is to avoid this unpleasant stimulation, the behaviour with which it is paired must be eliminated.

Food aversions also appear to be learned partly in this way. Children and adults, for example, tend to eat less of a particular flavoured ice-cream if ingestion has been previously

associated with an aversive stimulus such as an emetic, but not of others (Bernstein 1978; Bernstein and Webster 1980). The bitter taste has a genetic component which insures against the ingestion of noxious agents: most poisonous flora and fauna contain a quinine-like substance whose taste should dissuade a human organism from ingesting further. The liking for the bitter and pungent tastes of coffee and chilli is generally acquired via experience and develops during early adulthood (Zellner, 1991).

Rozin and Fallon (1981) and Fallon and Rozin (1983) suggest that food rejected by humans on psychological grounds have a predictable taxonomy: for a food to be rejected it is necessary that it is perceived as being (1) sensorily and affectively unpleasant to taste (usually those foods for which individuals develop a liking, e.g., black coffee, lima beans); (2) dangerous (rejection is based on anticipated harm: Examples include poison mushrooms, carcinogens); (3) disgusting (appearance on hands or in stomach is objectionable-usually animals or animal products such as faeces, or pork for Jews).

The possibility thus arises that the bingeing characteristic of emotional eating and bulimia nervosa might be alleviated on the basis of the knowledge of characteristic rejection of foods in non-bingeing subjects. Emotional eating and bulimia nervosa is characterised by an attempt at weight loss after binge eating through severe dieting, vomiting or laxative use. Prevalence estimates range from 2 to 10 percent of the general population (Fairburn & Cooper, 1983). The weight of the sufferer appears to be irrelevant to the incipience of the disorder (Mitchell, Pyle & Eckert, 1981) although the bulimic subject is likely to overestimate the size of her body significantly (Powers, Schulman, Gleghorn & Prange, 1987). One review has characterised the typical bulimic as Caucasian, female, in her mid-twenties, within the normal weight range and binges/purges from once a day to once a week (Schlesier-Stropp, 1984). The consequences of the bingeing and vomiting are severe. The effects of vomiting include swollen parotid glands, reduction of tooth enamel

by gastric acid, gastrointestinal disturbances and gastric and rectal irritation. Treatment for this disorder has included psychotherapy (Fairburn, Jones, Peveler, Hope & O' Connor 1993), antidepressant medication (Pope, Hudson, Jones, Yurgelun-Todd, 1983) and cognitive-behavioural therapy in which the patient is taught to consume enjoyable foods without vomiting afterwards (Rosen & Leitenberg, 1982), with, however, variable results.

(1) The treatment proposed here would affect the stimulus precipitating the bingeing and vomiting directly, namely, the food. There would seem to be little point in pairing the desired food with an emetic since bulimics in some cases characteristically regurgitate their food after the binge. One likely possibility might be to contaminate the food (without harming the subject) eaten by bulimics in order to alter significantly its taste. Chocolates, fries, milk, sweets may be impregnated with quinine, for example, which should radically alter the accustomed taste of the preferred foods. Although there is the possibility that texture and mouth feel also contribute to the choice of the bulimics' food, the variety of foods ingested suggests that it is their olfactory and gustatory components which primarily determine their selection. Aversion strength could then be tested against habit strength.

(2) Although the dominant component of food flavour is olfactory, the fact is frequently overlooked. The use of odour in classical conditioning paradigms in humans has not met with much evident success presumably because the conditioned stimulus is too weak to alter the unconditioned response. Interestingly, however, one of the primary responses to the perception of any odour is hedonic with responses elicited along a pleasantness-unpleasantness dimension. With food odours, one would imagine that this response would be considerably marked especially since food odour carries with it quite robust emotional and affective connotations (usually one of pleasure pre-prandially, displeasure post-prandially or disgust with certain off-odours or taints). It is plausible that a robust enough odour-possibly a food odour or an off-odour- would be potent enough to condition an

individual against the ingestion of a food if that particular odour accompanies it. The Foreyt and Kennedy (1971) example above is a persuasive indicator. Odours in the repugnant category may include asafoetida (an ingredient in some Indian cooking but which alone, and to some, is repulsive), rotting vegetables and meat, and hydrogen sulphide (rotten eggs). It is important to note, however, that one case of bulimia with anosmia and partial ageusia resulted in little reduction in the bingeing (Fahy, DeSilva, Silverstone and Russell, 1989). Preference for the texture of food was manifested as was an increase in sugar and salt added to foods.

(3) It is also highly likely that some stimulation of the trigeminus, implicated in the Tanner and Zeiler (1975) and Baumeister (1978) studies, might bring a cessation of eating. The inhalation of ammonia is a potent arouser and can be acutely painful. The stark, reliable and replicable effects of ammonia, which may inhibit behaviour, could therefore be applied to inhibit the bingeing bouts characteristic of emotional eating by repeatedly pairing the stimulus with ingestion. The potency of trigeminal stimulation would suggest that the contiguity of arousal/pain and eating would be highly associative. The ingestion of food during bingeing or even the sight of the food to be consumed might therefore set off an aversive reaction. It may, of course, be possible to condition aversion at an earlier stage-while the subject imagines gross food consumption, while the food is presented to her. The methodologies for these experiments will need to be examined closely.

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