THE ROLE OF BIOLOGICAL RHYTHMS AND BLOOD GLUCOSE LEVELS IN MAINTAINING A POSITIVE MOOD STATE.

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A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy

April 2008

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ABSTRACT

Although the effects of both the menstrual and circadian cycles on mood have been well documented, the question of whether the two interact to influence mood has not yet been addressed, despite evidence for such an interaction on other variables. Blood sugar level is a major contributor to the mediation of mood and is easily regulated by dietary intervention; there is also evidence that it is influenced by both the menstrual and circadian cycles. The present research takes a positive psychological approach to managing mood; the aims were to identify where natural variations in mood occur in relation to its underlying physiology, taking an applied approach to suggest ways of effectively managing positive mood and maintaining psychological well-being. A series of studies was carried out to measure fluctuations in mood in relation to biological rhythms, and in response to cognitively demanding situations and simple interventions. Mood was measured throughout the research using the UWIST Mood Adjective Checklist. The most consistent results were in relation to the Energetic Arousal dimension. This was shown to be influenced by both the menstrual cycle and the time of day, as well as an interaction between these two factors, and was consistently related to changes in blood glucose levels. Energetic Arousal also appeared to be more sensitive to the effects of the suggested interventions. Diurnal changes in mood throughout the course of a normal day were more evident among women in their premenstrual to menstrual phases, and also become more apparent in response to cognitive tasks. Trait Anxiety was a mediating factor in how individuals reacted to such tasks. Mood was closely related to blood glucose levels, and raising blood glucose to a robust but safe level effectively

enhanced positive mood in cognitively demanding situations. Oral contraceptives generally tended to eliminate menstrual cycle-related effects on mood and responses to intervention. It was concluded that mood states among healthy women are influenced by a complex interplay between biological rhythms, physiological states, individual differences and the context in which these moods take place. Simple interventions that can easily be incorporated into one's daily routine may be efficacious in maintaining a positive mood state, which has beneficial implications for psychological well-being.

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ACKNOWLEDGEMENTS

To thank everyone who has had some impact on the course of the last 8 years would probably be a thesis in itself. First and foremost my thanks go to my Director of Studies, Dr. Neil Morris, whose support and guidance got me through even the darkest and most difficult times (with the help of some feline friends). Dr. Brian Wink and Dr. Kevin Hogan for being part of my supervisory team and providing valuable input into the path of this research project.

My late mother Elena and my father Franco, for always giving me the best they could and being proud of me no matter what. My sister Dawn, proof that we *can* choose our relatives, for always being there for me through one crisis to the next. My brother Jack for never failing to make me smile. All my friends, old and new, who have supported me and kept me sane during this long and torturous process – you know who you are and I cannot thank you enough. I love you.

I would also like to thank Prof. Ken Manktelow for giving me useful advice from the very earliest stages, and as the independent assessor for my MPhil to PhD transfer. Also Prof. Peter Croft and Dr. Martin Frisher for being supportive of my studies throughout my employment at Keele University. Finally, I would like to thank Dr. Tony Cassidy and Dr. Jane Carstairs for examining this thesis, and for their very helpful comments.

Thanks to all.

1. LITERATURE REVIEW

1.1 A Positive Psychobiological approach to the well-being of women: Wider aims and theoretical basis

1.1.1 Mood, health and well-being

Perspectives on health are continually changing. Modern definitions of health have moved away from the traditional medical model, according to which a 'healthy' state was merely the absence of disease. Instead, current perspectives acknowledge the role of psychological factors so that 'health' is seen as a more generalised condition that incorporates 'well-being'. Well-being refers to physical and mental states being positive rather than neutral (Sanderson & Ruddle, 1992); in other words, the presence of good physical and mental health is just as essential as the absence of disease or illness in achieving a healthy state. Psychological well-being can hence be defined as a state of predominantly positive mood states (Kahneman, 1999). This may be one reason why holistic healthcare is becoming more popular. Holistic healthcare concentrates on both physical and psychological well-being simultaneously to provide an optimal balance.

As Morris and Wickes (2007) point out, this balance is not always maintained and care of physical well-being often dominates. Whilst relatively minor physical problems such as cuts or grazes tend to be dealt with immediately, mild negative shifts in mood and psychological well-being are often disregarded until they become more serious. Coping mechanisms to regulate the effects of these shifts (e.g. see Dew, 1996) possibly reduce the immediate threat they pose compared with the potential harm that could arise from

physical damage or dysfunction. Nevertheless, the relationship between physical and mental states means that avoiding psychological distress is central to maintaining not just good mental health, but also a healthy physical condition.

The biopsychosocial model of health (Kazarian & Evans, 2001; Engel, 1977, 1980) extends the medical model by incorporating psychological and social factors, asserting that all three components affect and are affected by an individual's health. The two-way nature of this model is important. Whilst it is clear that physical ill health can be accompanied by anxiety and depression, the resulting psychological state may in turn impede the recovery or stabilisation of medical conditions, thus producing a vicious circle in which well-being is difficult to attain (Evans, Hucklebridge & Clow, 2000). A number of medical conditions are linked to stress, such as irritable bowel syndrome (Blanchard, 2001), asthma (e.g. Lehrer *et al.*, 2002) and migraine headaches (e.g. Robbins, 1994). Likewise, stronger immune function has been associated with high levels of social support (e.g. Esterling, Kiecolt-Glaser & Glaser, 1996) and hardiness (Dolbier *et al.*, 2001), both of which may modify experiences of stress (e.g. Cottington & House, 1987) and its physiological manifestations (Karlin, Brondolo & Schwartz, 2003).

What constitutes 'stress' and subsequently 'stressors' is in itself a complex issue, with discourses of stress in relation to health and illness dating as far back as the 14th century (Lazarus, 1993). Arguably, its definition within this context will depend largely on the social structure within which it takes place. Cassidy (2001) questions the usefulness of stress terminology, asserting that it is now so widespread that it can be used to 'explain everything and as a result explain nothing' (p.10). Cassidy provides a wider definition of stress as a lack of 'fit' between a person and their world, leading to physical

or psychological illness. This is a particularly important viewpoint in the present research, not only because of the impact the changing roles of women may have on their well-being (see section 1.1.2), but also because it acknowledges the greatly individual and subjective nature of how an individual interacts with their environment.

Despite the broadness of definitions encompassing stress, it is arguably a relatively pervasive state. In preventing stress among healthy individuals, a useful starting point is everyday mood state. Mood itself is labile rather than stable (see 1.2.1) and may fluctuate throughout the day for a variety of reasons. Thayer's (1989, 1996, 2001) theory of mood fits a biopsychosocial approach to maintaining psychological well-being as it takes into account the underlying physiology of mood as well as external factors. Thayer's framework underpins the methodology used in the present research, and is described further in section 1.2. The biopsychosocial model is particularly useful in explaining how mood states are influenced by the biological and social contexts in which they occur, and the implications that these mood states have for physical and psychological well-being. This is the main focus of this thesis and will be elaborated throughout the subsequent sections.

1.1.2 Women and health

Even from the earliest developments in medicine women's health has been viewed as distinct from that of men, with great emphasis on reproductive functions and the accompanying psychological processes. The association between the female reproductive system and psychological dysfunction dates back to the ancient Greeks, who believed that symptoms of hysteria were caused by the uterus (hyster) wandering around the

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abdominal cavity – hence the concept of the 'wandering womb' (McKay, 1901). Hysterical symptoms continued to be associated with femininity, particularly the uterus, long into the 19th century (Showalter, 1987); medical and social advances since then might have improved understanding of the processes underlying these ideas, yet the true extent of this is debatable.

Despite the pervasive view that women were medically 'different', until recently women were excluded from clinical trials (see Kornstein & Clayton, 2002). Results from men were simply assumed to be generalisable across both sexes, with no consideration of physiological or psychosocial differences. Recent decades have seen an increased interest in women's health, not just in terms of reproductive processes but in all areas of health, such as the presentation of illness and response to treatment. Mental health remains a major focal point.

From an epidemiological point of view, 'in no field is women's health more worthy of attention than in mental health' (Kornstein & Clayton, p. xiii). Prevalence data for numerous psychiatric disorders certainly support this assertion. In two major community-based surveys of psychiatric disorders in the United States, depression was been found to be twice as common in women as in men (Regier *et al.*, 1988; Kessler *et al.*, 1993). Lifetime prevalence rates of major depressive disorder (MDD) followed a similar trend (Kessler *et al*, 1993), with a female-to-male relative risk of 1.7. A similar sex ratio was observed for lifetime prevalence rates of dysthymia (Kessler *et al*, 1994). More recently a worldwide study by the World Health Organisation (WHO) of sex differences in psychological problems in primary care (Maier *et al.*, 1999) found a 2:1 female-to-male prevalence ratio for current, remitted, first-episode and lifetime MDD.

Mood episodes and disorders are more prevalent among women, with the exception of manic episodes, which have similar rates for both sexes (Kessler *et al*, 1994). Comorbidity in bipolar disorder (i.e. the co-presence of other psychiatric disorders such as anxiety or eating disorders) is more common among women, with a greater likelihood of impaired recovery from mania (Strakowski *et al.*, 1992; Black *et al.*, 1988; Blehar *et al.*, 1998). Anxiety disorders such as panic disorder, agoraphobia, specific phobia, generalised anxiety disorder and posttraumatic stress disorder have been estimated to have lifetime prevalence rates two to three times greater in females than in males (see Breslau *et al.*, 1997; Yonkers *et al.*, 1996; Kessler *et al.*, 1994; Boyd *et al.*, 1990; Joyce *et al.*, 1989; Regier *et al.*, 1988; Robins *et al.,* 1984). Eating disorders are more common in females than males (Striegel-Moore *et al.*, 1998; Andersen & Holman, 1997), particularly anorexia nervosa, for which 95-97% of cases are female.

Whilst such disorders are by no means exclusive to women, or any less important in men, it is necessary to ask why they are more prevalent among women. Walker (1997) challenges biological explanations of women's mental health and illness (see section 1.3), posing the question of whether women really are victims of 'raging hormones' as purported throughout history. A biopsychosocial view would not discredit the role of hormones altogether, but at the same time placing epidemiological studies in their sociocultural context sheds an alternative light on the prevalence statistics.

The role of women in society has undergone major transformations throughout the last century, particularly during the last 50 years – yet the advantages of increased gender equality appear to have come at a price. Female roles have been added to rather than altered, resulting in 'role conflict' among many women. 'Role conflict' refers to the

'psychological effects of being faced with two or more sets of incompatible (or contradictory) expectations or demands' (Unger & Crawford, 1996, p. 463). Whilst a woman in paid employment will be expected to display full commitment and competence in her position, showing equality in terms of the traditional male model, she will also be expected to follow the traditional female model by giving highest priority to family; the experience of such role conflict has consistently been shown to be the case among most working women (Gilbert, 1993; Crosby, 1991). Difficulties in maintaining conflicting roles may lead to 'role overload' or 'role strain', whereby 'the demands of the roles outweigh the rewards and privileges' (Bernstein & Lenhart, 1993, p.176) – this may subsequently have detrimental effects on physical and psychological well-being. Indeed, studies have revealed that decreasing role strain within marriage reduces the incidence of women's mental and physical disorders (Helson & Picano, 1990; Steil & Turetsky, 1987). Support for the importance of social roles in maintaining well-being comes from studies of lesbian women. Lesbian relationships are characterised by less stereotyped roles and more equal distribution of power and workload, which have been linked to higher levels of relationship satisfaction (Greene & Herek, 1994).

Combining multiple roles can actually enhance physical and emotional well-being (see Shrier, 2002). Furthermore, the amount of stress involved in balancing work and family roles is lowered by factors such as a supportive partner, children being above preschool age, a high income and less job-related stress (Unger & Crawford, 1996). This suggests that taking measures to reduce role conflict and the associated stress experienced by women may have long-term benefits for well-being and reifies the appropriateness of a positive psychological approach.

There is clearly an abundance of evidence for the relationship between the social roles and situations of women and their mental health. It appears therefore that the pure biology of being female is not the determining risk factor in the development of mental illness. In spite of this, the effects of hormones have frequently been isolated as causes of diminished psychological well-being and even dysfunction. Dalton, who was one of the first to propose the concept of the 'Premenstrual Syndrome' (PMS) in the 1950s, asserted that PMS 'should not be a feminist issue' (1987, preface to 3rd edn.). A detailed review of the PMS literature is given in section 1.3.4, as well as a discussion of whether it is indeed appropriate to use such a label at all. Dalton argues that the condition is physiological and therefore a feminist perspective is irrelevant; yet within a biopsychosocial framework social context is important, hence one could argue that feminist issues are present in all aspects of women's health. Though it may be true that certain conditions or symptoms may occur regardless of context, the way in which an individual reacts to these states will inevitably be influenced by their physical and social environment. Consequently, the responses of others to these reactions will impact upon the individual to modify that response. Definitions, diagnoses, perceptions and implications of PMS and other conditions are often complicated by the changing roles of women, as discussed above, as well as social perceptions of female biology, which are elaborated upon in section 1.3.

1.1.3 Positive psychology and applications of the present research

Recently a previously undervalued perspective in psychology, positive psychology, has become influential (Seligman, 2000). One facet of this approach is the idea that psychology should concern itself with preventing psychological dysfunction – that is, the

maintenance of psychological well-being. Psychology takes on the role of a prophylactic against the effects of stressors. From this perspective, the present research concentrates on managing mood, identifying natural fluctuations so that measures can be taken to keep mood at optimal levels during times where it is likely to be less positive than usual. Fluctuations in mood according to menstrual cycle phase (see section 1.3) and time of day (see section 1.4) have been well documented, but to date the possible interaction between these factors has not been addressed with regards to mood, despite evidence for a menstrual-circadian interaction with other variables (see section 1.5).

A further issue regarding biological rhythm influences on mood is that much research has tended to focus on the negative aspects, or on situations where negative moods have already led to or developed into pathological states. This is most often the case regarding the menstrual cycle; a great deal of research on menstrual cycle-related fluctuations in mood, particularly from the 1970s to 1990s, concentrated on the Premenstrual Syndrome and other associated problems, with the aims to find a cure or solution. The positive psychological approach being taken here is twofold: firstly, the research concentrates on maintaining psychological well-being among healthy women. Secondly, cyclical variations in mood among these women are interpreted in terms of natural processes rather than being pathologised.

One of the main applications of mood management is in the context of the working day. There is a substantial body of literature on workplace stress and useful coping methods (e.g. see Morris & Raabe, 2001), though this *per se* is not the focus of this thesis – the workplace is considered as the context in which stress and mood changes take place and not the cause, which is a different matter to that of everyday moods and

should be tackled accordingly. Although negative mood and stress may be triggered by events that occur during the day, such patterns may be taken home and 'rehearsed' (see Martino & Morris, 2004). If this is the case then a 'prevention rather than cure' strategy may be appropriate; the overall level of stress experienced throughout the day is likely to be less severe if one begins with a calmer 'baseline'. Given the major changes that have taken place in relatively recent years with regards to women in the workplace, this area is particularly pertinent to the topic of women's health and the social issues that surround it. Thus the aims of the present research are to identify where natural variations in mood occur in relation to its underlying biology, taking an applied approach to suggest interventions for effectively managing positive mood and maintaining psychological well-being on an everyday basis.

The strategies suggested are based on 'self-medication' and regulation. Common methods of mood enhancement and regulation are covered in more depth in section 1.2. Morris & Wickes (2007) advocate the enhancement of psychological well-being in simple, practical, affordable ways, without the use of drugs. This is an appropriate approach in this case, as the research concentrates on maintaining well-being among healthy members of the population and does not seek to propose methods of treating psychological dysfunction. Thayer (2001) discusses the many ways in which people self-medicate, such as smoking, drinking alcohol, consuming chocolate and taking exercise. However, this concept is not as simple as it might seem. Morris & Wickes (2007) highlight the potential harm in many of these coping strategies, observing that although alcohol, nicotine or 'junk' food may temporarily enhance mood, they are simultaneously damaging to physical health. The authors also comment on the impracticalities of some of

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the healthier ways to enhance well-being; exercise, for example, may be contraindicated in some individuals, and requires sufficient motivation and discipline to commence and continue with the regimen so that the benefits are maintained. Similarly, meditation requires considerable skill that can be difficult to master. Therapies such as massage, though effective, may be beyond the financial reach of many members of society. Above all these techniques require time, which may not always be readily available to those who lead busy lives or have responsibility for others, such as single or working mothers.

Whilst positive changes in health regimen are to be encouraged, it is also important to acknowledge that not everyone will be at a stage where they feel they can initiate such changes. For this reason the present research aims are not to promote 'ideal' ways of enhancing psychological well-being, but to suggest simple, realistic strategies that fit into everyday routines and do not compromise physical well-being.

1.2 The measurement and physiology of mood

1.2.1 Defining and measuring mood

Mood is a labile state rather than a stable trait. With the exception of more pervasive states such as depression, moods are subject to change at a moment's notice and for a miscellany of causes. One might begin the day in a good mood and have it ruined by an accident or argument; on the other hand, a bad mood may be swiftly alleviated by a fortuitous event or unexpected compliment. Whilst the whimsical nature of mood is widely recognised, defining what it actually means is somewhat more complicated. Furthermore, scenarios such as these are relatively extreme; in reality, shifts in everyday mood tend to be more subtle and are regulated by a complex interaction of multiple factors.

Thayer (2001) describes mood as 'a background feeling that persists over time' (p.5), arguing that although moods have a great deal in common with emotions, they are not the same. Thayer observes that moods are often defined as less intense and longer lasting than emotions (again, depression is cited as an exception), usually without the obvious cause-and-effect relationship that exists between events and emotions (see Suzuki, 1970). Definitions of mood have generally been based on emotional reaction, though cognition has also been included as a component (see Mandler, 1975). Some mood states, for example 'thoughtful' or 'contemplative', do not necessarily have an emotional quality. Similarly, being 'in the mood' to do something describes disposition rather than emotional state (Thayer, 2001; Thayer *et al.*, 1988). Thayer does however point out two virtually universal concepts in theories and conceptions of mood. Firstly, most moods can be classified as either positive or negative, either in themselves or in the

feelings they produce. Secondly, moods are usually conscious. The latter in particular is central to the present research, as the methodology is based largely on the self-evaluation of mood.

A landmark study by Watson & Tellegen (1985) formed the initial basis for both the theoretical underpinning and methodology for the present research. Using factor analysis they identified just two factors, or dimensions, that accounted for most mood variations or feelings: *positive affect* and *negative affect*. Positive affect is associated with feelings such as enthusiasm and activeness, which have approximate opposites of lethargy and tiredness. Negative affect is associated with adjectives like jittery and nervous, which are approximately opposite to calm and relaxed. The central roles of energy and tension in this model and the basic moods they produce are evident in Thayer's theory of mood, which views the vast array of moods we experience as diverse interpretations of basic biological processes – specifically arousal levels. These concepts are based on Mandler's (1975) model, which describes moods and emotions as combinations of 'arousal and meaning analysis'; in other words, they result from the cognitive evaluation of autonomic responses to stimuli.

Thayer (1989; 1996; 2001) proposed a theory of four basic moods, which result from combinations of energy and tension: calm-energy, calm-tiredness, tense-energy and tense-tiredness. Whilst calm-energy is almost always a positive mood state and tense-tiredness negative, calm-tiredness and tense-energy can have both positive and negative connotations depending on their context. Calm-tiredness may be a very pleasant state in which to relax or retire to bed, but would be far from ideal at work or while participating

in sport. Conversely, a state of tense-energy may be conducive to working efficiently in certain situations, but would be less welcome during periods of rest or relaxation.

The optimal balance of energetic and tense arousal for maximum efficacy can be best explained by the Yerkes-Dodson law (1908). This law states that there is an inverted U-shaped relationship between arousal and performance. Moderate levels of arousal result in optimal performance; whilst very low levels lead to poor performance, over-arousal or negative forms such as anxiety are equally detrimental. When the Yerkes-Dodson law is applied to Thayer's model and considered in the context of the working day, it is apparent that calm-energy is the most desirable mood state. Calm-tiredness would mean being under-aroused and tense-energy would be likely to constitute over-arousal. Although calm-energy and tense-tiredness reflect similar levels of arousal, tense-tiredness comprises more negative forms of arousal – hence, within this framework, calm-energy is the ideal state for optimal performance and more positive mood during the working day.

However, whilst this two-dimensional approach to defining mood and its optimal states provides a useful starting point for defining the aims of the present research, assessing mood purely in terms of arousal does not give a complete picture of an individual's unique state at any given point. Morris & Wickes' (2007) concept of 'mood space' is a three-dimensional model that encompasses the actual pleasantness of mood alongside arousal states. Based on the three principal dimensions of the UWIST Mood Adjective Checklist (UMACL; Matthews, Jones & Chamberlain, 1990), this model defines mood as an individual's position in a three-dimensional 'mood space', so that scores on the Energetic Arousal, Tense Arousal and Hedonic Tone scales are analogous

to longitude, latitude and elevation. This does not contradict Thayer's framework; rather, it builds upon it to provide a more accurate indicator of one's current mood state. It is for this reason that the UMACL is the primary scale used throughout the present research. Only the three reliable subscales of Energetic Arousal, Tense Arousal and Hedonic Tone are included; a full explanation of this scale and its psychometric properties can be found in section 3.3.1.

The UMACL builds upon Thayer's Activation-Deactivation Adjective Checklist (ADACL; Thayer, 1967, 1978, 1986) so that the overall pleasantness of mood (as measured by the Hedonic Tone scale) can be compared with levels of Energetic and Tense Arousal. Moreover, the principal subscales of the UMACL balance positive and negative items rather than being biased in either direction. As mood is a subjective state, the only way to measure it is via subjective means. Nevertheless, it is still important to avoid biased responses. The use of negatively-oriented scales and the response they elicit is particularly an issue in menstrual cycle research, and is elaborated in section 1.3. Care must therefore be taken when selecting test instruments to ensure that such bias is minimised.

The unbiased nature of the UMACL is perhaps one reason why it has been used to measure mood in a wide variety of research applications. It has been used to assess affective response to a number of interventions, including glucose ingestion (Martino & Morris, 2003), aromatherapy baths (Morris, 2002) and slow tempo exercise (Naruse & Takane, 2000). The UMACL has also been useful in evaluating mood states in relation to cognitive situations or events. For example, Liu, Graham & Zorawski (2008) used it to define pleasant versus aversive arousal in order to determine its effects on memory.

Similarly, Brinkmann & Gendolla (2007) used it to define dysphoric mood states when testing the effects of dysphoria and task difficulty on cardiovascular response. A more population-specific study by Morris *et al.* (1998) used it to examine the relationship between mood and self-perception of cognitive competency among pregnant workers. This is by no means an exhaustive account, but demonstrates the versatility of the UMACL in mood research within both experimental and applied settings. Its sensitivity to even subtle shifts in mood makes it an appropriate tool for measuring changes in mood over specified time periods or in response to situations or interventions. In addition, it is the ideal tool with which to consider these changes within Thayer's broader mood framework and the more precise concept of mood space.

Thayer's theory of mood takes into account the underlying physiology of mood as well as environmental and situational factors; according to Thayer, moods are not solely mental reactions but are closely related to bodily states. Such a view fits the biopsychosocial model of health, as explained in section 1.1, and can be elaborated using Morris and Wickes' (2007) mood space model. This is the approach adopted in this research, which looks at changes in mood in relation to biological rhythms (the menstrual and circadian cycles) and corresponding changes in blood glucose levels. Blood glucose level is one major factor that has been attributed to changes in mood, and it has also been shown to vary diurnally and across the menstrual cycle.

1.2.2 Maintenance of blood glucose levels

In healthy, young individuals blood glucose levels are maintained at approximately 5 mmol/l via a negative feedback loop. When blood glucose rises above 5 mmol/l (towards

a hyperglycaemic state) insulin is released from the pancreas, which results in glucose being removed from circulation and immobilised as glycogen in the liver and muscles. When blood glucose levels drop below 5 mmol/l (towards a hypoglycaemic state) the pancreas releases glucagon that releases glycogen from the liver; the glycogen is broken down into glucose and released into the bloodstream, increasing blood glucose until insulin release is triggered. Insulin and glucagon are therefore mutually inhibiting. Deviations from the 'set point' for blood glucose, which tend to be due to the absorption of glucose from the gut, are rapidly regulated, whereas the mobilisation of glycogen means that blood glucose can be maintained even in early starvation. Tight control of blood glucose is essential because the brain uses glucose as its 'fuel' but cannot store it - brain processes rely on a constant supply of glucose from the bloodstream.

The efficiency of this particular homeostatic mechanism can be measured in terms of 'glucose tolerance'. Glucose tolerance refers to the capacity to metabolise glucose, i.e. the ability to return to baseline values quickly; following a meal, blood glucose levels rise for approximately 20-30 minutes, peak, then gradually return to pre-meal levels (Bellisle, 2002). Young and healthy individuals should have quite good glucose tolerance and will tend to metabolise sugary drinks and snacks fairly quickly. This is an important consideration for this thesis, as the participants in the studies reported were relatively young and in good health; the generalisability of some findings and consequently the appropriateness of certain interventions need to be evaluated in the right context.

Another important factor in glucose metabolism is the glycaemic index (G.I.) of the food being consumed (Jenkins *et al.*, 1981). The G.I. system ranks foods according to the impact that their carbohydrate content will have on blood glucose levels. High G.I.

foods will release energy very rapidly, resulting in a 'spiking' of blood glucose levels, whereas low G.I. foods will release energy much more slowly and steadily. The G.I. of a food depends on numerous factors such as the type of carbohydrate, and any fat, protein and acid it contains. Potatoes, for example, have a very high G.I. when eaten alone, but adding cheese (which is high in both protein and fat) will lower the G.I. by slowing down the gastric emptying rate.

Despite the body's ability to adapt when glucose is less readily available to the bloodstream, these situations are not ideal. At the same time, measures taken to remedy such situations need to take into account the impact of foods consumed not only on immediate physical and mental states, but also on potential well-being in the long term. The literature reviewed in the subsequent sections here indicates that mood and cognitive processes are impaired by a lack of glucose and suggests that the extent to which the body can compensate by mobilising glycogen is limited. Given that beginning the working day having taken in few, if any calories since the previous evening is commonplace, ameliorating such situations is a worthwhile focus in attempts to maintain well-being.

1.2.3 Blood glucose levels, cognitive performance and mood

Given that glucose is the brain's major fuel, it is logical to infer that psychological functions and processes will be affected by alterations in blood glucose levels. This assumption has been corroborated by numerous studies, often with compelling results. Benton and Owens (1993) demonstrated correlations between increased blood glucose levels and feelings of energy with reduced tension. Gold *et al.* (1995) supported these

results using the reverse manipulation; they demonstrated that inducing hypoglycaemia using insulin infusions raised tension and lowered energy. This association was replicated by Owens *et al.* (1997), who found that falling blood glucose levels corresponded to a drop in subjective energy. What is particularly interesting about the two latter studies is that they suggest that avoiding hypoglycaemia, rather than increasing blood glucose levels *per se*, is the crucial factor in maintaining a positive balance of energetic and tense arousal.

These findings were extended by Martino & Morris (2003), who showed that a glucose-enriched drink not only led to a more calm-energetic mood state, but also improved the overall pleasantness of mood (as measured by the Hedonic Tone scale of the UWIST Mood Adjective Checklist). This study is documented in greater detail in section 4.3.2, with the published version in Appendix A. Morris (2008) enhanced the ecological validity of this approach by testing the effects of chocolate on mood, concluding that a chocolate snack could reduce perceived tension in people with good glucose tolerance without raising blood glucose levels beyond the normal range. A common factor in these studies is that the glucose ingested was sufficient to raise blood glucose to a robust, but not excessively high level, which supports the view of glucose maintaining positive mood by avoiding or correcting hypoglycaemia. Research into the role of glucose and blood glucose levels in cognitive functioning and performance provides further evidence for this relationship.

A number of studies have shown glucose ingestion to have beneficial effects on cognitive performance. Lapp (1981), for example, found that higher blood glucose levels resulted in improved recall of word lists. Benton and Sargent (1992) found that memory

for spatial material and word lists was better after eating breakfast. A later study by Morris and Sarll (2001) showed that imbibing a glucose drink improved listening comprehension in students who had missed breakfast, ameliorating the effects of low blood glucose levels resulting from fasting. More recently, Morris (in press) demonstrated an increase of approximately 20% in the amount of information retained from a public safety video following a glucose drink; in this study the participants had eaten breakfast, suggesting that the glucose served to maintain blood glucose at optimal levels. Again, these results point towards a hypoglycaemia avoidance, or blood glucose maintenance hypothesis. This is supported further by evidence that consuming glucose may help enhance memory at the consolidation phase (Morris, 2007), suggesting that glucose serves to provide 'fuel' for the metabolic processes associated with learning.

A possible determinant of these effects is cognitive demand. Cognitive demand can be explained in terms of the mental effort required to complete a task; mental effort investment thus refers to energy mobilisation in the service of cognitive goals (Gaillard, 1993; 2001). Increased cognitive demand means greater mental effort investment: in other words, tasks that require greater mental effort, or have higher cognitive demand, necessitate increased energy mobilisation. This represents a compensatory strategy to 'protect' performance when task demands are augmented (Hockey, 1993; 1997). According to Mulder (1986) mental effort investment falls into two categories: 'task effort', which is a response to the computational demands of the task itself (e.g. time pressure, multi-tasking or high working memory load) and 'state effort', which is a response to non-task specific or environmental conditions (e.g. effects of fatigue, sleep deprivation or noise). Yet it is important to consider the two-way nature of the

relationship between mental effort investment and mental state. Whilst fatigue or tension may increase the mental effort investment required, the reverse may also be true – mental effort investment has psychological costs (Hockey, 1993; 1997).

Fairclough and Houston (2004) purport that the affective costs of increased mental effort investment may be the result of declining blood glucose levels. Increased cognitive demand has been found to accelerate the absorption of glucose from the bloodstream (Scholey et *al.*, 2001; Donohoe & Benton, 1999). Accordingly, Donohoe & Benton (1999) also found poorer cognitive performance among individuals with high or stable blood glucose levels, suggesting an impaired ability to transport glucose efficiently from the blood to the brain. This fits the association between good glucose tolerance and improved cognitive performance in young people (Owens & Benton, 1994). Depletion of blood glucose levels whilst undertaking activities of a cognitively demanding nature may thus contribute to a decline in positive mood state. Subsequently, working frequently throughout a state of glucose depletion, or even hypoglycaemia, may eventually have detrimental implications for psychological well-being in the long term.

Whilst glucose ingestion may well have beneficial effects on both mood and cognition, it is important to take into account the extent and duration of these effects. As Thayer (1989) points out, 'sugar-snacking' can rebound as the initial energising and tension-reducing effects can induce later fatigue and tension. On a practical level this is likely to impair cognitive performance, as a state of tense-tiredness constitutes a negative form of arousal (see section 1.2.1). In addition, doing this regularly may again have detrimental effects on psychological well-being in the long term, not just from directly

inducing a tense-tired state, but also from the negative effects on mood that may arise from reductions in cognitive functioning within an occupational or educational setting.

1.2.4 Circadian rhythm effects on blood glucose levels

Blood glucose appears to follow a circadian rhythm, with higher levels observed during the morning compared with the afternoon (Troisi, Cowie & Harris, 2000a; Bolli & Gerich, 1984; Bolli *et al.*, 1984). This diurnal variation in blood glucose could provide some explanation for diurnal variations in mood, which are discussed in more detail in section 1.4.

A study by Thayer (1987) showed that patterns of self-reported energy following a sugar snack or brisk walk were different for subjects tested in the morning compared with those tested in the afternoon; although both groups in both conditions showed an immediate increase in energy, afternoon subjects showed a more rapid decline following both interventions. Positive effects of glucose ingestion on mood might therefore depend partly on endogenous rhythms of both blood glucose and mood.

1.2.5 The menstrual cycle and blood glucose

Evidence for menstrual cycle-related changes in blood glucose tends comes mainly from studies of diabetic subjects. Lunt and Brown (1996) found that 61% of 124 women with type 1 diabetes reported perimenstrual changes in blood glucose, with the commonest pattern being a premenstrual rise in glucose. This supports previous studies that have recognised menstrual cycle-related changes in glycaemic control (Walsh & Malins, 1977; Cramer, 1942). Although the prevalence of women reporting such changes was higher

than that observed in some earlier research (Steel, 1985; Walsh & Malins, 1977), it was similar to that observed in a more recent study (Cawood, Bancroft & Steel, 1993). 56% (69 subjects) also reported cyclical changes in appetite - of these 69 subjects 78% increased their food intake premenstrually, with an increase in the consumption of high-fat foods being the most common change. 71% of the 69 also noted perimenstrual changes in capillary glucose, whereas only 49% (27) of the 55 women not reporting any cyclical changes in appetite noted perimenstrual changes in capillary glucose. These findings support suggestions that menstrual cycle-related changes in blood glucose and insulin requirement are due to changes in appetite and subsequent changes in food consumption (Cawood, Bancroft & Steel, 1993).

The Lunt and Brown (1996) study also found that perimenstrual changes in capillary glucose levels were not eliminated by the use of oral contraceptives. This is consistent with findings that cyclical changes in food cravings are not affected by oral contraceptives (Hill & Heaton-Brown, 1994; Bancroft & Rennie, 1993). By contrast, Troisi, Cowie & Harris (2000b) found that nondiabetic oral contraceptive users had slightly lower levels of fasting blood glucose than non-users, supporting previous findings (e.g. Kjos *et al.*, 1993; Godsland, Crook & Wynn, 1990; Perlman *et al.*, 1985). The issue of oral contraceptive use looks to be potentially important and is covered further in section 1.3.5.

1.3 The menstrual cycle and its effects on mood

1.3.1 Social perspectives on menstruation: Historical and cultural influences

Attitudes towards women's health throughout history, as discussed in section 1.1, have stemmed largely from menstruation, with this uniquely feminine phenomenon attributed as a cause and effect to a variety of pathological states. What is most interesting about these attitudes is their inexorable link to beliefs about femininity and female power. The Ancient Greeks' theories on the 'wandering womb' (McKay, 1901) clearly illustrate the association made between femininity and weakness. This association is arguably still present to this day, though the relationship between this alleged 'weakness', femininity and power has undergone marked shifts over time.

Within Western cultures 19th century views on menstruation were largely of a pathological and destructive process, a sign of the uterus 'crying' for a baby (see Martin, 1989). Menstruation represented failure to conceive, which constituted failure to fulfill the expected female role. The inability to recognise menstruation as being natural and normal was possibly the result of it being a considerably less common occurrence than it is today. As Guillebaud (1984) points out, it is only in relatively recent years that women have not spent most of their reproductive years either pregnant or lactating. The fact that many women are disturbed by the absence of menstruation with the use of certain oral contraceptives (see section 1.3.5) is, according to Guillebaud, a reflection of modern women having become accustomed to menstruating regularly and not borne out of genuine physiological necessity.

Scambler and Scambler (1993) highlight the impact that social expectations have on medical perspectives, asserting that science is 'neither fully autonomous nor fully value-neutral…' but '…a social institution' (p.23). Furthermore, the patriarchal values from which negative definitions of menstruation have arisen not only reflect the culture of the time, but have in turn been legitimised and reinforced by medicine. Ehrenreich and English (1978) put forward the rather sinister view that social roles encouraging women to be 'sick' were in the interests of the doctors themselves, whose obligation to find the causes of such 'sickness' enabled them in turn to propose theories that justified these roles. Doyal and Elston (1986) take this further to explain how the idea that women were harmed by mental rather than physical work not only reinforced the perception of women as inferior, but also justified the different lifestyles of working-class and middle-class women.

Though it has been argued that the connection between femininity and mental frailty persisted long into the 19th century (Showalter, 1987), the evidence shows that it did not stop there. The American writer Florence King's (1985) autobiographical account of her grandmother's attempts to raise her as the perfect 'Southern Lady' during the early to mid 20th century provides an insightful description of how ill gynaecological and mental health were considered to be not only linked, but a badge of honour. Although the connection between female hormones and weakness was still being made, the connotations were positive rather than negative:

"One of the joys of growing up Southern is listening to women argue

about whether nervous breakdowns are more feminine than female

trouble, or vice versa… These two afflictions are the *sine qua non* of female identity and the Southern woman is not happy unless her family history manifests one or the other." (p.15)

In a society where femininity was so highly prized, and at the same time defined in terms of alleged weakness, it could be argued that displaying such 'weakness' actually gave women more power. Yet the obverse is that women were relinquishing control by allowing themselves to be defined by their hormonal states, or rather society's perceptions of these states. One might assume that this contrasts starkly with the modern day scenario, where the emphasis is on sexual equality; however, the recognition of problems associated with female hormones and the menstrual cycle has remained a double-edged sword.

1.3.2 The physiology of the menstrual cycle

The normal menstrual cycle lasts from 25 to 35 days, with an average of 28-30 days. It is regulated by interactive relationships between the hypothalamus, pituitary gland, ovaries and adrenal cortex and consists of four main phases (see Ojeda, 1992; Guillebaud, 1984). *Menstruation* lasts about four to five days. The *follicular phase* is also known as the 'proliferative' phase and lasts 10 to 16 days. At the start of the menstrual cycle, a hypothalamic releasing factor induces the anterior pituitary gland to produce a follicle-stimulating hormone (FSH) so that a number of ova start to develop. Usually only one develops completely and the rest die. The developing ovarian follicle secretes the hormones oestradiol and oestrone, known collectively as oestrogen; the increased level of

oestrogen in circulation is responsible for the reconstruction and proliferation of the endometrium (lining of the uterus). It also stimulates the pituitary to produce lutenising hormone (LH) by means of hypothalamic feedback. The *ovulatory phase* lasts around 36 hours. When the concentration of LH reaches a peak the mature follicle bursts, releasing the ovum through the wall of the ovary. It then passes into the uterus via the fallopian tube. The *luteal phase* is the second half of the menstrual cycle and lasts 14 days. The influence of LH causes the original site of the ovum to develop into a secretory organ called the corpus luteum, which secretes oestrogen and progesterone. This prepares the endometrium for implantation in the event of fertilisation and also inhibits the pituitary from producing FSH and LH via negative feedback. If fertilisation does not occur, the corpus luteum stops secreting oestrogen and progesterone; the endometrium degenerates and is expelled during menstruation. Without the inhibitory effects of oestrogen and progesterone the hypothalamus is able to once again stimulate the pituitary to release FSH, so that a new cycle begins.

The second half of the menstrual cycle tends to be constant. Assuming fertilisation does not take place, menstruation will almost always occur 14 days after ovulation. The follicular phase, which is highly variable, determines the length of the cycle.

1.3.3 Physical symptoms

Abdominal sensations just before or at the onset of menstruation are experienced by the vast majority of menstruating women. Dysmenorrhoea ('period pain') has been reported to affect approximately 52% of the postpubescent female population, with over half of

these women also suffering from one or more systemic symptoms such as nausea, vomiting, diarrhoea, headaches, fatigue, nervousness, dizziness and, in very severe cases, fainting and collapse (Ylikorkala & Dawood, 1978). In most cases this pain occurs in the absence of any pelvic abnormality and is therefore defined as 'primary dysmenorrhoea'.

Bickers (1941) proposed that primary dysmenorrhoea was caused by irregular or uncoordinated contractions of the myometrium (uterine muscle), as opposed to the regular, high-amplitude contractions associated with nonpainful periods. He found that contractions of abnormally high amplitude only occurred in ovulatory cycles, defined by the presence of a corpus luteum, which led him to propose that primary dysmenorrhoea was the result of increased concentrations of progesterone. Bickers hypothesised that administering large doses of oestrogen during the first half of the menstrual cycle would eliminate contractions of abnormally high amplitude by either preventing ovulation or by inhibiting LH production by the anterior pituitary. Ylikorkala and Dawood (1978) developed this further, concluding that dysmenorrhoea was due to a secretory endometrium and raised progesterone levels - these increase the production and release of endometrial prostaglandins that stimulate the myometrium to contract during menstruation. More recent studies have provided support for this view, particularly those involving the use of prostaglandin synthetase inhibitors in the treatment of primary dysmenorrhoea (Tolman, McGuire & Rosenthale, 1985; Dingfelder, 1981).

Bickers' early theory and its subsequent developments fit the now widely accepted concept that primary dysmenorrhoea is the direct result of ischemic hypoxia of the myometrium resulting from such abnormal contractions (Dawood, 1981; Friederich, 1983; Gannon, 1981; Lundström, 1981). The assertion that dysmenorrhoea only occurs in

ovulatory cycles has since been refuted as even women using oral contraceptives, which eliminate the normal menstrual cycle, may still experience painful periods (Richardson, 1992, pp. 5-6). However, oral contraceptives can help alleviate dysmenorrhoea and other menstrual symptoms (see section 1.3.5). Breast tenderness has also been found to be less severe in annovulatory cycles (Walker & Bancroft, 1990).

Moderate exercise has also been shown to affect the experience of primary dysmenorrhoea. Aganoff and Boyle (1994) found that exercisers reported less pain than non-exercisers, which contradicted previous reports of increased dysmenorrhoea in regular exercisers (Metheney & Smith, 1989) but was supported by a later study (Choi & Salmon, 1995). The discrepancy in findings was attributed to methodological flaws in the Metheney and Smith study; however, this is still not necessarily evidence for cause-and-effect in the implied direction. Rather than the reduced dysmenorrhoea being due to exercise, it is quite possible that experiencing less pain around menstruation facilitates exercising in the first place. This is just one example of how factors may interact to influence women's experiences of menstruation; furthermore, it illustrates the complex nature of the two-way relationship between physical health and psychological well-being.

1.3.4 The 'Premenstrual Syndrome'

There has been an immense body of literature published on menstrual cycle-related mood changes, particularly in recent years with the increased emphasis on Premenstrual Tension (PMT) or the Premenstrual Syndrome (PMS). The notion of PMS is taken almost as a given, with 'raging hormones' virtually an accepted norm. Shreeve (1983) published

one of numerous self-help books on PMS (referring to it as 'the curse that *can* be cured'), including such advice as:

> If you are stuck with a non-starter, skip it and ring for a mini-cab. Better a few pounds less in your account to spend on vodka and tights than a respectable bank balance and a car that ends up as a write-off, because in your understandable rage at its tardiness in starting you have wrapped it around a lamp-post! (p.75)

This is a classic illustration of both the medical model of menstrual cycle-related mood disturbances and the persistent association between female hormones and psychological well-being.

Many studies have indeed shown that mood varies during the menstrual cycle, particularly levels of anxiety or tension (e.g. Benedek & Rubenstein, 1939; Beaumont, Richards & Gelder, 1975; Golub, 1980; Garling & Roberts, 1980). The term PMT was first identified by Frank (1931) to describe the emotional disturbances associated with the luteal phase of the menstrual cycle. Greene and Dalton (1953) later proposed the term PMS, arguing that emotional tension formed only a part of the cyclical disturbances associated with the luteal phase. More recently, the term 'late luteal phase dysphoric disorder' (LLPDD) has been adopted as a more accurate description of this condition.

However, the concept that any such syndrome exists at all has been debated. It has been argued that premenstrual symptoms occur because of socially mediated expectations and beliefs (e.g. Parlee, 1974, 1982; Ruble & Brooks-Gunn, 1979) and that because of

these expectations, feelings that would 'under other circumstances be experienced as nonspecific states of arousal' (Parlee, 1980, p. 248) are labelled as premenstrual tension. Consequently, a common problem in menstrual cycle and mood research is the lack of differentiation between 'stress' and 'normal' states (Walker, 1997). This is partly a function of the actual scales used to measure menstrual experiences, which are often negatively oriented and seldom include positive items. The Menstrual Distress Questionnaire (MDQ; Moos, 1968a), for example, has been widely used in menstrual cycle research, but its emphasis on negative experiences such as depression and irritability means that it is likely to elicit negative responses. Furthermore, participants may resort to stereotypical responses when completing the questionnaire retrospectively (e.g. Parlee, 1974).

This view of the pathologisation of menstrual symptomatology was echoed by Laws (1985), who argued that instead of asking 'do I have PMT?', the question should be 'why have the changes I am used to going through with my menstrual cycle become intolerable to me?' (p.58). Instead of viewing the fluctuations in mood associated with the premenstrual and menstrual phases as an illness or dysfunction, this alternative approach accepts such cyclical mood changes as a natural and normal process. This perspective has been supported by various studies indicating correlations between self-reported stress and self-reported PMS (e.g. Woods *et al.*, 1995; Warner & Bancroft, 1990). However, such findings are predominantly the results of correlational studies and therefore cannot suggest a cause-and-effect relationship. Glick, Endicott & Nee (1993) found that pairs of sisters showed very little similarity in their premenstrual changes

despite concordance on general menstrual and physical characteristics, which goes against the view of PMS as a socially mediated condition.

The debate surrounding the concept and definition of PMS has been addressed by Bancroft (1995), who argues that this term is used to explain too broad a variety of physical and psychological symptoms across the menstrual cycle. Bancroft proposed a 3-factor model of PMS, incorporating menstruation and its associated problems, timing and additional characteristics that would make a woman vulnerable to the first two factors. Research finding premenstrual severity of both physical and mood symptoms to be highly stable across cycles (Bloch, Schmidt & Rubinow, 1997; Hurt *et al.*, 1992; Freeman *et al.*, 1985) also provides evidence for a genuine premenstrual syndrome.

Research indicating improved perimenstrual mood with oral contraceptive use as well as reduced physical symptoms (see section 1.3.5) suggests a hormonal basis for the premenstrual syndrome. Progesterone has been the main hormone implicated because in the natural menstrual cycle, it is present only in the luteal phase. Progesterone in sufficient doses has also been found to have a tranquilising or anaesthetic effect (Maxson, 1988). Nevertheless, the relationship between ovarian hormones and perimenstrual mood is by no means clear-cut. The general conclusion is that although hormones appear to play a major part in physical symptoms, PMS sufferers are hormonally indistinguishable from asymptomatic women where emotional symptoms are concerned (Walker, 1997). Changes reported by women taking oral contraceptives are thought to occur because suppression of the normal menstrual cycle disrupts their usual hormonal pattern (Parry, 1994; Bancroft, 1993; O'Brien, 1993; Walker, 1992a).

Despite the vast body of literature on the causes of PMS and its variant forms, its actual prevalence has been the subject of much speculation. Dalton (1987) asserted that premenstrual 'mood swings' occur in at least half of all women, describing these as on a continuum with a 'minor nuisance' (e.g. reacting to a trivial irritation or making a cutting rebuke) at one extreme and a 'major catastrophe' (e.g. violent verbal abuse or smashing objects) at the other; even further lies the possibility of 'suicide, homicide or infanticide' (p. 32). This fits the *International Classification of Diseases*, 10th revision (ICD-10; WHO, 1996), whose criteria for PMS include mild psychological discomfort as well as physical symptom such as bloating, weight gain, breast tenderness, swelling of breasts, hands and feet, general aches and pains, and disturbances in concentration, sleep and appetite. Only one symptom is required for a diagnosis of PMS, although it must occur within the luteal phase and cease with or shortly after menses onset.

Criteria for Premenstrual Dysphoric Disorder (PMDD), as set out in the appendix of the *Diagnostic and Statistical Manual of Mental Disorders*, 4th revision (DSM-IV; APA, 1994), are considerably more restrictive, even though PMDD is not actually classified as a psychiatric disorder. Application of these criteria requires women to chart their symptoms daily for at least two consecutive menstrual cycles; complaints must include one of four core symptoms (irritability, tension, dysphoria and lability of mood) and a minimum of 5 out of 11 total symptoms. These symptoms should have occurred with most cycles over the last year, and must have caused social, occupational and lifestyle disruptions (APA, 1994). As with ICD-10 criteria the symptoms should show clear premenstrual onset and menstrual remission; furthermore, a change in symptoms of at least 50% from the follicular to luteal phase is suggested for a PMDD diagnosis (Steiner

et al., 1995). According to these criteria, just 3-8% of women of reproductive age are affected (Angst *et al.*, 2001; Merikangas *et al.*, 1993; Ramacharan *et al.*, 1992; Rivera-Tovar & Frank, 1990; Johnson *et al.*, 1988; Andersch *et al.*, 1986). The symptoms reported among these women are primarily to do with mood, and are severe enough to cause serious lifestyle and relationship disruptions (O'Brien *et al.*, 1995; Freeman *et al.*, 1985). Whilst non-drug treatment has proved successful in some cases (Freeman & Rickels, 1999), women fulfilling these criteria for PMDD do not generally respond to conservative interventions (Steiner & Born, 2002). This suggests that the 'premenstrual syndrome' does exist, and that some women do experience psychological disturbances due to hormonal pathology. In such instances a medical model is probably more appropriate, and the use of drugs or interventions to treat the condition is likely to be of benefit.

For these women, it could be argued that approaching the problem in this way may even give them greater control over it. Giving PMS/PMDD a label that identifies it as an 'illness' or medical condition that may be treated or even 'cured' may help sufferers to reclaim the sense of control that may be lost while experiencing these disturbances (see Scambler & Scambler, 1993). On the other hand, the mere suggestion that these experiences are beyond a woman's control positions her as a victim of 'raging hormones' – a perspective that is not altogether helpful (see Walker, 1997). The balance possibly lies in the degree of symptomatology. Whilst severe cases might benefit from having an explanation for their feelings, negative labelling of natural fluctuations in mood among the normal population could potentially be harmful. The recognition and normalisation of menstrual cycle-related mood changes is empowering in the sense that menstruation itself

is accepted as a natural and normal process, but remains debilitating in the prevailing assumption that it will automatically cause and/or explain disturbances in mood. It is worth considering the view of Pfaff *et al.* (2004), who purport that hormones do not 'cause' behaviour; they simply influence responses to stimuli. Whether 'stimuli' constitute environmental, situational or additional physiological factors, it is inappropriate to define cyclical mood changes purely in terms of hormonal status.

1.3.5 Oral contraceptives

Oral contraceptives abolish the natural menstrual cycle; the bleeding that occurs during scheduled breaks in many oral contraceptive systems is the result of hormone withdrawal rather than a normal menstrual period (Guillebaud, 1984, pp.38-40). Because of this oral contraceptive users have often been excluded from studies of menstrual and premenstrual symptoms as the cyclical changes they experience may differ from those experienced during the natural menstrual cycle. However, the widespread use of oral contraceptives means that is important to consider any effects they might have (Richardson, 1992, p.12).

There is considerable evidence to suggest that oral contraceptives alleviate paramenstrual symptoms. Hood and Bond (1959) reported a clinical trial of the first oestrogen and progesterone contraceptives, which indicated that the majority of users would experience some relief of premenstrual symptoms. Nilsson, Jacobson and Ingemanson (1967) found that the majority of their subjects reported improvement or disappearance of premenstrual symptoms such as depression and irritability during the administration of an oral contraceptive. Other studies have supported these findings, indicating that oral contraceptive users tend to report less severe paramenstrual symptoms

than women with natural cycles (e.g. Rouse, 1978; Moos, 1968b; 1969). More recent studies, however, have suggested that premenstrual symptoms are unaffected, sometimes even aggravated, in oral contraceptive users (Bancroft & Rennie, 1993; Bancroft & Sartorius, 1990).

Oral (or hormonal) contraceptives can be divided into four main categories: 21-day combined, phasic combined, progestogen only and depot contraceptives. Combined oestrogen-progestogen contraceptive pills work by suppressing ovulation, causing the endometrium to become thin and hypoplastic and thickening cervical mucus. 21-day combined pills are available with a variety of oestrogens and progestogens in different doses, providing a steady hormone intake for 21-days followed by a 7-day break. Phasic combined pills work in a similar way to 21-day pills and can be subdivided into two main types: biphasic and triphasic. With phasic pills the hormone content is varied throughout the cycle according to natural hormone levels so as to decrease overall hormone intake. Progestogen-only contraceptives are thought to cause premature endometrial secretory patterns, thicken cervical mucus and disrupt tubal transport; ovulation and menstruation are completely suppressed in some women but not in others. Depot contraceptives can be subdivided into three main types: intramuscular, subdermal and intrauterine. They work in a similar way to progestogen-only pills, releasing a progestogen over a prolonged period ranging from 8 weeks to 5 years, depending on the device.

Differences have been found in the ways in which oestrogen and progesterone affect paramenstrual symptoms. Bickers (1941) found that large doses of oestrogen administered during the first half of the menstrual cycle eliminated painful contractions of the myometrium during menstruation; subcutaneous administration of progesterone,

however, had no effect upon dysmenorrhoea, which fits his theory outlined above (see *Physical symptoms*). These findings were supported by Magos *et al.* (1986), who found that oestradiol (a form of oestrogen) helped relieve paramenstrual symptoms. In contrast Gillman (1942) found that large intravenous doses of progesterone appeared to induce paramenstrual symptoms at other points in the menstrual cycle, whereas Filler & Hall (1970) found that exogenous progestogens relieved dysmenorrhoea. More recently, Bancroft & Rennie (1993) found that triphasic pill users tended to report more negative mood symptoms than those using the combined pill and non-users. The differences between early and more recent findings are possibly due to the greatly reduced doses of hormones in modern contraceptive pills.

Despite some discrepancies, there is considerable evidence that the alteration (or abolishment) of the menstrual cycle via the use of hormonal contraceptives has subsequent implications for its accompanying mood states. This and the widespread use of oral contraceptives in contemporary society makes it necessary to take into account patterns of use within the present study samples and, where possible and appropriate, their effects.

1.3.6 Food preference and consumption across the menstrual cycle

The evidence for menstrual cycle influences on food craving and consumption is often contradictory and points towards another complex relationship. Several studies have found that menstrual cycle phase affects eating behaviour. Bowen and Grunberg (1990) gave subjects nine different foods (three sweet, three salty and three 'bland') and asked them to rate the foods on taste judgement scales. Sweet food consumption and preference

ratings were higher in the premenstrual period; restrained eating did not vary, although low restraint (suggesting reduced cravings) was associated with fewer general menstrual symptoms and slightly better mood. The authors link these changes in food preference and consumption to the higher levels of oestrogens and progestins during the premenstrual phase. The phase effects reported are consistent with those of Hill and Heaton-Brown (1994), who found that cravings for all types of food measured (chocolate-based, sweet and savoury) increased premenstrually and decreased during the menstrual to postmenstrual phase compared with the follicular phase. Further support comes from the findings of Rogers and Jas (1994), whose subjects showed a 61% greater energy intake (i.e. increased intake of both sweet and non-sweet, high-fat, high-carbohydrate items) during the premenstrual phase.

Kanarek, Ryu and Przypek (1995) found no menstrual cycle-related changes in preferences for foods with varying levels of salt and fat. This contradicts the findings of Hill and Heaton-Brown (1994) and Rogers and Jas (1994), but not Bowen and Grunberg (1990), who only found changes in cravings for sweet foods. Despite the apparent consistency in reports of premenstrual cravings for sweet foods, the exact reasons remain unclear. Ottley (2000) reviews the literature on food and mood; where the menstrual cycle is concerned, it is concluded that cravings for sweet foods are indeed more frequently reported premenstrually. However, it is pointed out that fat and protein intake is increased as well as carbohydrate intake (Vlitos & Davies, 1996), which suggests that such cravings are due to appetite rather than specific carbohydrate cravings. This supports previous research (Barr *et al.*, 1995), which is consistent with Hill and Heaton-Brown's (1994) conclusion that the cravings reported were directed at reducing hunger

and improving mood through the consumption of pleasant-tasting food rather than being the result of specific nutritional needs.

Evidence that menstrual cycle effects on mood and eating occur independently (Rogers & Jas, 1994; Bowen & Grunberg, 1990; Bancroft, 1988) give reason to suggest an endocrine rather than psychological basis for these cravings. Yet the issue is complicated by the lack of evidence for oral contraceptive effects (Hill & Heaton-Brown, 1994; Bancroft & Rennie, 1993) - as oral contraceptives abolish the menstrual cycle and eliminate many of its associated symptoms (see section 1.3.5), one would expect a similar reduction in cyclical food craving.

The exact relationship between food, mood and the menstrual cycle is ambiguous; the problem with much of the research carried out on this topic is that it is difficult to define the causal factors. Nevertheless, the influence of blood glucose levels on mood (see section 1.2.3) along with evidence for both menstrual cycle (see sections 1.2.5 & 1.3.4) and circadian rhythm (1.4.2 and 1.4.4) effects on both blood glucose and mood mean that eating behaviour is an important point to consider when interpreting results.

1.4 Circadian rhythm effects on mood

1.4.1 Circadian rhythms and their regulation

Biological rhythms are defined in terms of how often they occur. The word 'circadian' refers to those occurring approximately once every 24 hours, or once a day. The sleep-wake cycle is the most obvious circadian rhythm, although core body temperature and hormones such as corticoids, glucose, testosterone, melatonin and prolactin also follow very regular 24-hour patterns. Circadian rhythms are functions of both endogenous circadian clocks, and entrainment by external cues (see Pfaff, Phillips & Rubin, 2004).

In mammals, circadian rhythms are controlled by the activity of neurons within the suprachiasmatic nucleus (SCN), which is located in the hypothalamus. This 'master clock' governs 'slave clocks' in most peripheral cells synchronised to the SCN, which produces circadian rhythms of hormone levels and associated behaviours (Pfaff *et al.*, 2004). The clock is regulated by external cues (*zeitgebers*), the main one of which is light. The SCN is located above the optic chiasm, enabling a retinohypothalamic tract to maintain its synchronisation with the light and dark cycle; glutamate is the main neurotransmitter involved in this process.

The endogenous component of circadian rhythms is evident in the presence of 'free-running' rhythms that exist even in the absence of zeitgebers. The typical free-running period for the sleep-wake cycle is not 24, but approximately 25.3 hours (Wever, 1979). In other words, an individual living in an environment devoid of temporal cues, such as changes in light and dark, will fall asleep roughly every 25 hours. This not only demonstrates the biological nature of circadian rhythms, but also illustrates the interactive role of environmental factors in maintaining these rhythms. Though largely intrinsic,

circadian rhythms are to an extent entrained by external influences. This is particularly of relevance to the blood glucose aspect of this research project, due to the role of established meal times in maintaining levels of glucose throughout the day.

1.4.2 Time of day effects on mood

Various studies have demonstrated circadian influences on mood. Diurnal mood variation in healthy subjects (McCann *et al.*, 1993; Monk *et al.,* 1992; Wood & Magnello, 1992; Brendel *et al.*, 1990; Taub & Berger, 1974) suggests that mood has an underlying circadian component; later, Boivin *et al.* (1997) found that mood varied significantly with circadian phase. This is likely, at least in part, to be a function of circadian rhythms of temperature and various hormones (see section 1.4.4), as well as the sleep-wake cycle itself.

Thayer (1989) describes the typical pattern of mood variation throughout the day. In most individuals, mood is fairly low upon waking and increases gradually throughout the morning, peaking late morning to early afternoon and reaching a low point mid afternoon, before increasing to a sub-peak early evening. There are deviations from this norm, with some people being extreme 'morning' or 'evening' types (Thayer, 1989; 1996; 2001). How accurate people's self-definitions are of their own 'type' is questionable. However, Gibertini, Graham and Cook (1999) found that self-report of circadian type (morning, afternoon or evening) was strongly related to melatonin acrophase (the time at which melatonin levels in the blood peak during the 24-hour cycle), suggesting that people are indeed able to reliably rate their circadian type. Melatonin has also been implicated in mood (see section 1.4.4).

1.4.3 Circadian sleep theories: Evidence from sleep deprivation studies

Although sleep deprivation studies have been conducted largely to answer the question of whether sleep is necessary for some recuperative purpose, or simply an evolved response to the light-dark cycle, they have also provided useful information on diurnal variations in mood and arousal. From an evolutionary perspective, it makes sense for humans to be alert and active during daylight hours and inactive at night, when vision is poor and the risk of predation is high. This would explain the typical diurnal fluctuations in mood described above (1.4.2) and how these relate to other circadian rhythms (see section 1.4.4), although modern living has complicated this relationship somewhat.

The sleep cycle itself consists of four distinct stages, measured primarily by electroencephalogram (EEG). Just before sleep the human EEG is punctuated by alpha waves (8 to 12 Hz); the onset of sleep sees a sudden transition into initial stage 1, which has a low-voltage, high-frequency EEG similar to that of active wakefulness. As the individual progresses through the subsequent stages, voltage gradually increases and frequency decreases. Stage 2 sleep has a slightly higher amplitude and lower frequency EEG than Stage 1; it is also characterised by K complexes, which are large, biphasic EEG waves, and sleep spindles, which are 1 to 2 second bursts of 12 to 15 Hz waves. Stage 3 sleep has occasional delta waves, which have a frequency of 1 to 2 Hz and are the largest and slowest EEG waves. Stage 4 sleep consists mainly of delta waves; once this stage has been reached the individual will stay there for a period before retreating back through the stages. Unlike initial stage 1, emergent stage 1 sleep is accompanied by rapid eye movements (REMs) and a loss of core muscle tone. This stage is thus referred to a REM

sleep, with stages 2, 3 and 4 referred to collectively as non-REM (NREM) sleep. Each cycle lasts approximately 90 minutes.

There is evidence that there may be some recuperative or restorative purpose to sleep (e.g. Blagrove, Alexander & Horne, 1995; Lorenzo *et al.*, 1995; Gillberg, Kecklund & Åkerstedt, 1994; Corsi-Cabrera, Ramos & Meneses, 1989). For example, Lorenzo *et al.* (1995) found that changes in the waking EEG are dependent on the amount of previous sleep or wakefulness, with a decrease in EEG power following sleep. It could therefore be inferred that increased EEG power is the result of a greater effort to remain awake, thus indicating some recuperative element to sleep. Nevertheless, many sleep deprivation studies have demonstrated strong support for circadian sleep theories. Research on the effects of one or more nights without sleep on cognitive performance have shown that rather than deteriorating progressively over the sleep deprivation period, effects on performance tend to be time-dependent, with low points occurring during times of typical inertia (e.g. Lorenzo *et al.*, 1995; Babkoff, Caspy & Mikulincer, 1991). Accordingly, self-ratings of sleepiness are also increased during these times (Babkoff *et al.*, 1991; Dinges, Orne & Orne, 1984).

The importance of self-perception of tiredness and its influence on physical state is illustrated by Rodgers *et al.* (1995). They examined self-paced walking and self-ratings of mood and fatigue over a 48-hour period of wakefulness, comparing participants undergoing sleep deprivation in conjunction with continual performance of physical work tasks with sleep-deprived only controls. The majority of physiological parameters, namely muscle contractile properties, anaerobic power measures, resting blood glucose and lactate concentration remained unaffected in both groups, despite a significant

decline in performance on all physical work tasks in the experimental group. A decline in cardio-respiratory function was found in the controls; the authors suggest that positive physical responses to the actual performance of physical work tasks among the experimental group outweighed the negative responses to sleep deprivation. Yet in spite of the absence of evidence for detrimental physiological effects of sleep deprivation, the experimental group showed a significant deterioration in self-selected walking pace and mood, with an increase in perceived workload by 32 hours compared to 48 hours in the controls.

The most relevant finding here is the evident importance of psychological factors in response to sleep deprivation. It was clear that the sleep deprived individuals, whether they were performing physical tasks or not, had the physiological capacity to do so. Furthermore, the experimental group was no more affected than the controls. Thus, the influence of psychological variables such as mood and perception of effort appeared to be the cause of their decline in performance. This not only goes against a recuperative theory of sleep on a physical basis, but also highlights the importance of subjective factors in maintaining well-being. As stated by Gillberg *et al.* (1994), subjective measures of sleepiness and mood are 'the only information on which the individual bases his decisions about whether to discontinue work to avoid mistakes or accidents'. On a less immediate and more long-term scale, subjective perception of one's own psychological state is the only information on which the individual assesses the potential impact of the current situation on future well-being. In addition, this perception is likely to be influenced by an interaction between that situation and endogenous biological rhythms.

1.4.4 The relationship between mood and other circadian rhythms

Whilst it is again important to remember that hormones do not necessarily 'cause' behaviour (Pfaff *et al.*, 2004), their influence upon reactions to stimuli or situations makes hormonal rhythms a useful consideration in understanding diurnal fluctuations in mood. Unlike the menstrual cycle, circadian rhythms and associated mood changes are not subject to pervasive stereotypes and social expectations; interpreting circadian mood rhythms is therefore arguably less confounded, even with the myriad of situational factors that may impact upon mood state.

This does not, however, mean that social factors are any less significant in their impact. Beersma and Gordjin (2007) highlight the potential dangers of being a 24-hour, 7 days a week society now that the availability of electricity allows us to be active at any hour at will. They argue that given the relatively slow evolution of circadian processes it may take generations before we are biologically adapted to such an unpredictable environment, warning that too little is known about the negative effects this may have on well-being and performance. Following Cassidy's (2001) definition of stress as a lack of 'fit' between an individual and their environment, it is clear to see how this forced contradiction of natural bodily states has the potential to lead to impaired physical and mental health. In addition, the complexity of real-life situations means that models of circadian processes are always simplifications of reality, as it is impossible to take into account every possible regulating factor.

This is particularly true in the case of glucose, which appears to follow a circadian rhythm of higher levels during the morning compared with the afternoon (Troisi, Cowie & Harris, 2000a; Bolli & Gerich, 1984; Bolli *et al.*, 1984). Reilly and Waterhouse (2007)

describe the diurnal nature of patterns of food and fluid ingestion as largely being synchronised to the sleep-wake cycle, although other factors such as social circumstances and the habits or choices of the individual or family will also influence meal times. Again, the emphasis is on choice; just as electricity enables us to be active at will, the ready availability of food means that we are no longer restricted as to when we can eat. Subsequently, the entrainment of blood glucose level rhythms by meal times is likely to be disrupted. In a pure research study of circadian blood glucose rhythms, this would be a problem that could only be resolved by using a sample adhering to a fixed food regimen controlled by the experimenters. In a naturalistic study of diurnal changes in blood glucose levels and mood, this is not necessarily problematic but nevertheless important to consider when interpreting results.

The two-way relationship between physiology and behaviour is by no means limited to glucose. Testosterone levels in men follow a clear diurnal pattern, tending to be highest in the morning and lowest in the evening (Pfaff *et al*., 2004; Kraemer *et al.*, 2001). Whilst excessive levels lead to an increase in aggression, levels themselves may be affected by external factors such as a current wish for children (Pfaff *et al*., 2004). Similarly, cortisol secretion follows a circadian rhythm that is closely related to the sleep-wake cycle, with peak concentrations around 7:00 to 8:00 a.m. and virtually no secretion from midnight to around 4:00 a.m., yet levels are increased dramatically with stress (see Pfaff *et al*., 2004). This illustrates the complexity of the relationship between hormones, mood and behaviour and the link between physical and psychological well-being, as discussed in section 1.1.

The role of the sleep-wake cycle in the regulation of other circadian rhythms and their subsequent effects on mood is evident. Several studies have reported a link between mood levels and circadian rhythms of melatonin and core body temperature (e.g. Boivin & Czeisler, 1998; Wright *et al.*, 1997; Badia *et al*, 1991; Åkerstedt & Froberg, 1977). During the night, when melatonin is high and body temperature is low, positive mood is decreased along with alertness and performance. During the day, when melatonin is low and body temperature is high, positive mood, alertness and performance are enhanced. From an evolutionary perspective, it makes sense for arousal and responsiveness to be decreased during hours of darkness, and increased during waking hours. Despite advances in technology interfering with the natural sleep-wake cycle, it will take considerably longer to alter these established circadian rhythms (see Beersma and Gordjin, 2007). Because of this it is important to consider their role in the management of everyday moods.

1.5 The menstrual-circadian interaction

1.5.1 Rationale for considering a menstrual-circadian interaction

The circadian rhythm and mood research reviewed in section 1.4 indicates that both sexes display diurnal variations in mood. On the surface, it would appear that sex is not an important factor in this. However, as demonstrated in section 1.3, women's moods may also be influenced by menstrual cycle phase. Where menstrual cycle phase is not taken into account for studies of circadian mood patterns, it is likely that cycle phase at the time of testing will differ among participants. Thus, variations in mood as a result of cycle phase may be masked.

If, for example, mood is generally less positive during menstruation (see section 1.3.4), this could impact upon diurnal mood patterns in two possible ways. Firstly, mood might simply be less positive over the course of the day during that phase, resulting in the same diurnal pattern, only less positive than it would be at other phases. Alternatively, it may exacerbate negative mood shifts that occur as a function of the time of day, or perhaps exert selective effects upon specific mood dimensions - which would cause the 'typical' diurnal pattern itself to be altered. In either case, grouping women in the menstrual phase with those who are tested during the mid-cycle would cancel out these effects. Testing participants during specified cycle phases, or at least taking this into account as a factor, would reveal whether diurnal changes in mood are consistent across the menstrual cycle, or whether diurnal shifts in mood are altered by cycle phase.

For the purpose of identifying where individuals may be more vulnerable to negative moods, this is an important consideration. It also highlights the complexity of

everyday moods, and the numerous factors involved that make it difficult to examine any one variable in isolation.

1.5.2 Sex differences in sleep patterns

According to the report of the National Commission on Sleep Disorders Research (1993), 'most of what is known about sleep – its physiology, normative values, and consequences of sleep deprivation – has been obtained only for males'. As with numerous other fields within psychological research (e.g. see Richardson, 1992), women were often excluded from sleep research for reasons including the possible confounding effects of the menstrual cycle. This, as Manber and Armitage (1999) point out, is a matter of concern as it sheds doubt on the findings and conclusions that have failed to pay attention to factors unique to women, such as menstrual phase at the time of participation. Later research suggests that these concerns are valid (see section 1.5.3).

Several species, including humans, display sexually dimorphic sleep patterns (Manber & Armitage, 1999). For example, women have twice as many sleep spindles (Gaillard & Blois, 1981) and more slow-wave sleep (Reynolds & Shipley, 1985) compared to men, as well as a differential time course in delta activity (Dijk, Beersma & Bloem, 1989) and a slower age-related decline in delta (Ehlers & Kupfer, 1997). These differences are exacerbated by external factors such as drug administration, sleep deprivation, shift work and travel across different time zones (Armitage & Hoffmann, 1997). These findings not only indicate that sex hormones affect sleep, thus supporting the notion of a menstrual-circadian interaction, but also emphasise the role of outside

influences and lifestyle choices on entrained and evolved rhythms, as discussed in section 1.4.

Studies of humans support evidence from animal research indicating that gonadal hormone receptors exist in the central nervous system and influence sleep. A detailed review of these animal studies can be found in Manber & Armitage (1999). Both endogenous and exogenous oestrogen and progesterone have been found to affect sleep patterns. During and after the menopause, when oestrogen and progesterone decrease, women have longer latencies to sleep onset (Santoro *et al.*, 1996) and more sleep maintenance insomnia (Hunter, 1992; Brugge, Kripke & Anconi-Israel, 1989; Santoro *et al.*, 1996; Ballenger, 1976) compared with pre-menopausal women. This is consistent with epidemiological studies reporting increases in the incidence of insomnia complaints (Lugaresi, Cirignotta & Zucconi, 1983) and hypnotic use (Hunter, Battersby & Whitehead, 1986) among menopausal women. One factor that may be involved is the occurrence of 'hot flushes' among this population (Shaver & Paulsen, 1993; Shaver *et al.*, 1988; Erlik, Tataryn & Meldrum, 1981); the relationship between female hormones and temperature is elaborated below (1.5.4).

Exogenous hormone administration also exerts an influence on sleep patterns. This has both theoretical implications and practical relevance, given the widespread use of oral contraceptives containing oestrogen and progesterone. The sedative effects of progesterone on both women (Blumer & Migeon, 1975; Itil *et al.*, 1974; Yalom *et al.*, 1968; Merryman *et al.*, 1954; Seyle, 1941) and men (Friess *et al.*, 1997; Schulz *et al.*, 1996; Carter-Little, Matta & Zahn, 1974; Cooper *et al.*, 1972) are well documented, and consistent with findings from animal studies (Bitran, Purdy & Kellogg, 1993; Landgren

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et al., 1987; Seyle, 1942). Moreover, evening administration of progesterone induces a significant increase in NREM sleep (Friess *et al.*, 1997). Progesterone and its metabolites 5α-pregnanolone and 5β-pregnanolone are believed to exert their sedative effects by acting as GABA$_A$ receptor agonists (Gee *et al.*, 1988); by contrast pregnenalone, a precursor of progesterone, acts as a GABA$_A$ antagonist (Majewska *et al.*, 1989; Majewska, Mienville &Vicine, 1988) to enhance delta EEG activity in NREM sleep (Lancel *et al.*, 1994), producing an effect opposite to the sedative properties of progesterone (Lancel *et al.*, 1996).

Oestrogen also has significant effects upon sleep patterns in women. Hormone-replacement therapy (HRT) using oestrogen alone has resulted in improved sleep quality in perimenopausal women, characterised by decreased latency to sleep onset (Polo-Kantola *et al.*, 1998; Brugge *et al.*, 1989; Regestein *et al.*, 1981; Schiff *et al.*, 1979), increased total sleep time (Schiff *et al.*, 1979; Thompson & Osswald, 1977) and decreased rate of cyclic alternating patterns (Scharf *et al.*, 1997). These improvements are more marked among women reporting greater insomnia pre-therapy (Polo-Kantola *et al.*, 1998). Similar effects have been observed for more contemporary HRT preparations that combine oestrogen and progesterone (Purdie *et al.*, 1995; Pickett *et al.*, 1989). These effects can be explained and elaborated by evidence for menstrual cycle effects on sleep.

1.5.3 Menstrual cycle effects on sleep

It seems ironic that during the 1970s and 1980s, when there was an abundance of literature on the menstrual cycle (see section 1.3), sleep research largely ignored its potential confounding effects; that is, when women were used as participants at all (Lee

& Shaver, 1985). Early studies did acknowledge this issue, but failed to actually address the problem, by obtaining norms for women during the follicular phase (Woodward & Freedman, 1994). Although more recent years saw some attempts to consider the possible interaction between the menstrual cycle and circadian rhythms, methodological complications and inconsistencies, particularly with regards to the temporal intervals of both the menstrual cycle and sleep measurements, make it difficult to draw direct comparisons between studies (Manber & Armitage, 1999). Subsequently, the relationship between the menstrual and circadian cycles is neither clear nor simple.

Nevertheless, evidence for menstrual cycle effects on sleep suggests that this relationship does indeed exist. Sleep continuity has been found to be dependent on menstrual phase, with the largest number of awakenings after sleep onset observed during the late luteal phase (Lee *et al.*, 1990; Parry *et al.*, 1989). As this is the phase in which both oestrogen and progesterone levels are declining, it fits the evidence given above (1.5.2) for the sedative effects of progesterone. Concordantly, the smallest number of awakenings was observed during the early luteal phase, in which levels of oestrogen and progesterone are increasing. These findings are consistent with reports of sleep spindle frequency being highest during the late luteal phase (Ishizuka, Usui & Shiraishi, 1989; Lee & Shaver, 1985; Besset, 1980) and a significant premenstrual decrease in slow-wave sleep (Ishizuka *et al.*, 1992; Lee *et al.*, 1990).

This decreased sleep continuity may be partly attributable to increased core body temperature at that time (Lee & Shaver, 1985; see section 1.5.4). It may also provide some explanation for reports of reduced energy premenstrually (see section 1.3.4), as well as a premenstrual increase in reports of daytime sleepiness among healthy women

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(Armitage & Yonker, 1994). Premenstrual sleepiness is more prevalent among women who display other premenstrual symptoms (Sachs, Persson & Hagenfeldt, 1982); this, however, does not necessarily infer cause-and-effect. Whilst the effects of sex steroids on sleep may lead to increased premenstrual sleepiness, it is also possible that other premenstrual symptoms may be the reason for increased feelings of tiredness and sleepiness. This is supported by a significant relationship between overall severity of premenstrual symptoms and self-reported daytime sleepiness, but not between symptom severity and decreased sleep continuity (Armitage & Yonker, 1994).

In addition, a more recent study by Takeuchi, Oshi & Harada (2005) concluded that circadian typology (i.e. 'morningness' vs. 'eveningness') was associated with menstrual disruptions in mood and physical state, with those experiencing more frequent mood fluctuations and/or menstrual pain tending to consider themselves more evening typed. Being morning typed was also associated with a more stable menstrual cycle. This could be linked to disrupted sleep continuity among those experiencing more severe paramenstrual symptoms. Indeed, the authors conclude that a physiological relationship between the circadian system, circadian typology and the menstrual cycle is demonstrated. Yet an alternative, or possibly additional explanation is that eveningness preference in women experiencing more severe paramenstrual symptoms might simply be a subjective reflection of increased tiredness resulting from the symptoms themselves. Once again direct causality cannot be inferred, and the importance of subjective factors in maintaining psychological well-being in relation to physiological variables is emphasised.

Further support for the relationship between the menstrual cycle and circadian rhythms comes from the use of sleep deprivation in the treatment of Premenstrual Dysphoric Disorder (PMDD). A number of studies have found this to be efficacious in reducing symptoms of major depressive disorder (e.g. Kuhs & Tolle, 1991; Gillin, 1983), as well as those specifically associated with PMDD (e.g. Parry *et al.*, 1995; Parry & Wehr, 1987), with improvement occurring following recovery nights of sleep. It is believed that PMDD symptoms may be linked to disturbed rhythms of temperature and cortisol, and that sleep deprivation might exert its therapeutic effect by realigning these rhythms with sleep (Parry *et al.*, 1995; Parry *et al.*, 2000). Although these effects are specific to a clinical population, it is clear that the menstrual cycle and diurnal rhythms have a combined role in the psychological well-being of women.

1.5.4 The menstrual cycle and circadian rhythms of temperature and melatonin

Core body temperature and levels of melatonin both follow distinct circadian rhythms and are closely associated with sleep and mood (see section 1.4.4). Reports of menstrual cycle-related differences in these circadian rhythms among normal subjects provide a physiological justification for examining the combined effects of the menstrual and circadian cycles on mood.

Temperature in particular is linked closely to the menstrual cycle, with measures of core body temperature used as relatively accurate predictors of ovulation and optimal times for conception (e.g. Royston, 1982). Moreover, diurnal changes in temperature are significantly altered by menstrual status. Higher nighttime temperature levels have been

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observed during the luteal phase of the menstrual cycle (e.g. Cagnacci *et al.*, 1996; Driver *et al.*, 1996; Lee, 1988; Rogacz *et al.,* 1988) and with oral contraceptive use (Kattapong, Fogg & Eastman, 1995; Lee, 1988; Webley & Leidenberger, 1986), whereas lower temperatures have been observed during the follicular (pre-ovulatory) phase (see Wright & Badia, 1999). Changes in thermoregulation may explain changes in sleep patterns related to the menstrual cycle (Shibui *et al.*, 2000).

The relationship between menstrual status and melatonin levels is more ambiguous. Some studies claim that melatonin levels are lowest immediately before ovulation and highest during the luteal phase (e.g. Brun, Claustrat & David, 1987; Webley & Leidenberger, 1986), whereas others report that melatonin is not affected by cycle phase (e.g. Ito *et al.*, 1993; Berga & Yen, 1990). Oral contraceptives have been shown in some studies to increase nocturnal melatonin levels (Brun, Claustrat & David, 1987; Webley & Leidenberger, 1986), but have been reported in others to reduce melatonin (Reinberg *et al.*, 1996) or to have no effect (Delfs *et al.*, 1994). Melatonin has also been linked to perimenstrual pathology, with PMDD patients displaying blunted melatonin rhythms (Parry *et al.*, 1997a; 1997b; 1990). It is asserted that this may be due to disturbances in the underlying circadian pacemaker or to its input pathways (Parry *et al.*, 1997b), which suggests that mood disturbances associated with the menstrual cycle are linked to circadian rhythms; however, it is not clear whether these circadian disruptions are the result of hormonal disturbances related to the menstrual cycle, or vice versa.

The relationship between female hormones and sleep (see section 1.5.2) suggests that the menstrual cycle may contribute to disruptions in sleep and its associated

circadian rhythms, even if the precise nature of the relationship itself is more complex. Sex differences in morningness and eveningness support this hypothesis. Gibertini, Graham and Cook (1999) found that female 'morning' types (as defined by self-reports and melatonin acrophase) reported more positive affect on waking than female afternoon or evening types - no such discrimination was found in males. This fits later findings of a relationship between morningness preference and menstrual stability (Takeuchi, Oshi & Harada, 2005). It also ramifies the efficacy of self-reports and self-preferences in determining one's own physiological states, which is a particularly important consideration in the present research given the interrelationship between these states, mood and well-being.

2. SUMMARY AND AIMS OF RESEARCH

2.1 Summary

Recent decades have seen a shift from 'traditional' female roles, with as much importance placed on women's positions in the workplace as in the home. Consequently, women may experience 'role conflict', which may in turn make them more vulnerable to mood disturbances and subsequent psychological disorders. Whilst medical models of women's health have tended to attribute such problems to hormonal states, particularly the menstrual cycle, others have questioned the appropriateness, and indeed usefulness, of pathologising natural and normal processes. The present research concentrates on healthy women, investigating natural variations in mood and considering ways to maintain a positive mood state where they may be more susceptible to negative changes.

The literature reviewed in section 1 suggests that there is an interaction between the menstrual cycle and circadian rhythms, but the research to date has not addressed the question of how mood may be affected by this interaction. This is the main research question and will provide the original contribution to existing knowledge of the inter-relationship between the menstrual cycle, circadian rhythms and mood, using an integrative biological rhythm model to define and explain cyclical mood changes. Overall the evidence reviewed suggests that such a relationship exists. Both body temperature and melatonin levels have an influence on mood, and there is also a menstrual-circadian interaction. Blood glucose level, however, appears to be a key factor and will be the main focus for the underlying biology of mood. Blood glucose is influenced by both the

menstrual and circadian cycles, and plays a major part in the regulation of mood and arousal. This perspective fits Thayer's (1989; 1996; 2001) theoretical framework, which relates mood and arousal to corresponding physiological changes. The present studies will consider mood as three-dimensional (see Morris & Wickes, 2007) using the three principal subscales of the UWIST Mood Adjective Checklist (Matthews, Jones & Chamberlain, 1990), so that mood is defined not just in terms of arousal states but also its overall pleasantness and relationship to somatic comfort.

Moreover, blood glucose is one variable that is largely, and automatically, self-regulated. This makes it an essential consideration in suggesting ways to prevent and ameliorate negative mood, particularly in cognitively demanding situations which may increase the need for glucose. Thus, emphasis will also be placed on applying the research to the management of mood in everyday contexts so that psychological well-being can be maintained when it is likely to be less than optimal, thus developing a positive psychological model of cyclical mood variation.

2.2 Aims and hypotheses

The primary aims of the present research are therefore to:

1) Identify natural variations in mood in relation to biological rhythms, i.e. the circadian and menstrual cycles;

2) Examine the relationship between mood and blood glucose levels, in relation to biological rhythms and in cognitively demanding situations;

3) Suggest simple interventions for maintaining a positive mood state, even when mood is likely to be less positive or more vulnerable to negative changes.

These aims will be achieved through the following study series:

1) Circadian rhythm studies

   These studies seek to identify diurnal fluctuations in mood during the course of participants' normal, everyday routines, and within a working context. Sex differences are taken into account as a preliminary investigation of the proposed menstrual-circadian interaction.

2) Menstrual cycle studies

   Menstrual cycle-related changes in mood are considered alone and alongside diurnal variations to examine the possible menstrual-circadian interaction in greater detail.

3) Blood glucose and cognitive task response studies

   These studies examine the relationship between blood glucose levels and mood, particularly in response to cognitively demanding situations. They build upon the circadian rhythm studies to consider time of day as a factor, providing some explanation of the physiology underlying diurnal mood variations and how moods are affected by cognitive tasks.

4) Blood glucose and biological rhythm studies

   Diurnal patterns of mood and blood glucose levels are compared, firstly without taking menstrual cycle phase into account, and then specifically in women in the

premenstrual to menstrual phases. This is to provide some insight into the physiology underlying diurnal mood changes, and on how these may be affected during the perimenstruum.

5) Intervention studies

Findings from the previous study series are considered in suggesting interventions for maintaining a positive mood state during the perimenstruum. These interventions are simple measures that can easily be incorporated into one's everyday routine in order to keep mood at a calm-energetic 'baseline' at times where it is likely to be less positive.

Thus, it is broadly hypothesised that:

1) Mood will vary both diurnally and across the menstrual cycle, with a possible interaction between these two rhythms, i.e. diurnal mood changes may be exacerbated at certain points in the menstrual cycle, and vice versa;

2) Mood will be related to blood glucose levels, i.e. low blood glucose will be associated with more negative mood;

3) Blood glucose levels will influence mood response within cognitively demanding settings;

4) The suggested interventions will have a positive effect on mood, even during the perimenstruum where it is likely to be less positive.

3. METHODOLOGY: DEFINING PHYSIOLOGICAL STATES

3.1 Determining menstrual cycle phase

The normal menstrual cycle lasts from 25 to 35 days, with an average of 30 days. It consists of four phases (see for e.g. Guillebaud, 1984): menstruation, the follicular phase, the ovulatory phase and the luteal phase. The follicular phase, which is highly variable, determines the length of the cycle and lasts 10 to 16 days. The second half of the menstrual cycle tends to be constant. Assuming fertilisation does not take place, menstruation (which lasts approximately four to five days) will almost always occur 14 days after ovulation. This 14-day period is the luteal phase (the late luteal phase being the premenstruum). Throughout the research, menstrual cycle phase is determined by self-report of the commencement of menstruation. Because the latter half of the cycle is constant, it is possible to use the date of menses onset to retrospectively calculate the occurrence of the other phases. More detailed information can be found in section 1.3.2.

The use of hormonal measures to support these estimates has been considered. However, the purpose of many of the studies described below is to establish cyclical fluctuations in mood during the participant's normal routine, so that the research can be applied to the management of everyday mood. The mood scales used are sensitive measures that are likely to be affected by prolonged periods of laboratory study. The complexities surrounding the accurate assessment of endocrine function are discussed by Griffin (1992). 'Convenient' methods for measuring hormone levels (i.e. urine testing

kits) have been criticised for lacking in accuracy, and would be unlikely to contribute information any more meaningful than that obtained from the current method. Furthermore, the basis of the research is primarily psychological rather than physiological; the main aim is to identify where natural variations in mood occur in relation to the more general underlying bodily state. Although the roles of hormones will be discussed in terms of possible explanations for the findings, identifying precise hormonal changes is beyond the scope of this study.

3.2 Measuring blood glucose levels

Throughout the research blood glucose levels are tested according to standardised procedures pre-approved by the University of Wolverhampton Safety Committee. Blood glucose levels are measured using Prestige Medical Healthcare Ltd. digital glucometers and BM-Test 1-44 testing strips, following the manufacturer's procedure. Self-testing equipment of this kind is commonly used by diabetics and provides quick, simple and convenient estimates of blood glucose, interfering minimally with current activity and the mood scales themselves. These particular instruments take readings from whole blood and use an algorithm to convert this to plasma equivalent so that the readings are expressed in mmol/l for plasma. Although this method has also been criticised for being less accurate than laboratory assays, the problem can be overcome (or at least reduced) by taking more than one reading and using the average.

3.3 Mood scales

3.3.1 The UWIST Mood Adjective Checklist (UMACL: Matthews, Jones & Chamberlain, 1990)

The UMACL consists of 29 adjectives used to describe the moods people may have, rated on a 4-point Likert scale. For each adjective, the respondent is required to circle the response that best matches how they feel, with 1 being 'definitely' and 4 being 'definitely not'. Respondents are required to complete the questionnaire quickly to describe how they feel at that moment, and not how they usually feel; because of this the UMACL is sensitive to even momentary shifts in mood, making it ideal for measuring responses to specific situations or interventions.

The UMACL comprises five subscales. The three main subscales are the factorial, bipolar scales of Energetic Arousal, Tense Arousal and Hedonic Tone. These three subscales all have good psychometric properties (Matthew, Jones & Chamberlain, 1990), so will be the only ones included for analysis in the present studies. The Energetic Arousal scale measures feelings of subjective energy, with items such as 'energetic', 'alert' and 'vigorous' on the positive end of the scale and negative items such as 'passive', 'sluggish' and 'tired'. Scores range from 8 to 32, with a higher score indicating a more energetic state. Tense Arousal measures feelings of subjective tension, with positive items such as 'nervous', 'tense' and 'jittery', and negative items such as 'relaxed', 'composed' and 'calm'. Scores range from 8 to 32, with a higher score indicating a more tense state. Hedonic Tone measures the overall pleasantness of mood, and is associated with feelings of somatic comfort and well-being (Morris *et al.*, 1998). Positive items include 'happy', 'cheerful' and 'satisfied', and negative items include

'sorry', 'depressed' and 'sad'. Scores range from 8 to 32, with a higher score indicating a more pleasant mood.

The UMACL also includes the Anger-Frustration subscale, which is a unipolar scale consisting of positive items such as 'impatient', 'annoyed' and 'angry'. It does not have a factorial basis and so should be interpreted with caution; however, it is useful when anger is of particular interest. The General Arousal provides an overall measure of arousal regardless of the pleasantness of mood. It is made up of positive and negative items taken from the Energetic Arousal and Tense Arousal scales; again, it does not have a factorial basis and therefore must be used with caution. Due to the reduced reliability of these subscales they have been omitted from analyses in the present studies.

3.3.2 The Dundee Stress State Questionnaire (DSSQ) (Matthews *et al.*, 2002)

The Dundee Stress State Questionnaire (DSSQ) was developed for 'comprehensive assessment of subjective states in performance contexts' (Matthews *et al.*, 2002, p. 317). There are two versions of the questionnaire – one for pre-task completion, and one for post-task – and each consists of four separate sections.

Part 1, Mood State, is the UMACL (refer above). All 29 items, and thus its usual subscales, are included. The questionnaire itself is identical in both the pre- and post-task versions; the only difference is that the pre-task questionnaire requires the participant to state how they are feeling at that present moment, whereas the post-task questionnaire is concerned with how they felt while performing the task.

Part 2, Motivation, concerns one's attitude to the task. The pre-task version refers to how the participant feels about the task they are about to perform, and consists of eight items rated on a 10-point Likert scale. This subscale is bipolar: four of the items are positively scored, with a high score indicating high motivation. For example, the question 'How motivated are you to do the task' is rated from 0 to 9, with 0 being 'not at all' and 9 being 'very much'. The other four items are negatively scored, so that a high score indicates low motivation. For example, the question 'How eager are you to do well at the task' is rated so that 0 is 'very eager' and 9 is 'not at all eager'. This subscale is a modified version of the NASA-TLX questionnaire (Hart & Staveland, 1988). It has a minimum score of 0 and a maximum score of 72.

The post-task version asks the same questions in reference to how the participant feels about the task they have just performed. Scoring is identical. Within this section on the post-task questionnaire a second subscale, Workload, is included. This is a unipolar subscale consisting of six items requiring the participant to rate the mental, physical and temporal demand of the task, as well as their performance, effort and frustration in completing the task, on an 11-point Likert scale, with 0 being 'low' and 10 being 'high'. It has a minimum score of 0 and a maximum score of 60.

Part 3, Thinking Style, is concerned with how the participant feels about themselves in relation to the task, i.e. how they feel their mind is working, how confident they feel, and how well they expect to perform. The pre-and post-task versions are virtually identical, except that the pre-task version asks the participant how they feel in relation to the task they are about to perform, and the post-task version asks how they felt

while completing the task. The scale consists of 28 items rated on a 5-point Likert scale, with 0 being 'not at all' and 4 being 'extremely'. It consists of four unipolar subscales.

The Self-focused attention subscale comprises eight selected items from the modified Fengstein *et al.* (1975) private self-consciousness scale and provides a measure of how introspective the participant feels they are being, including items such as 'I am trying to figure myself out' and 'I'm reflecting about myself' (in the post-task version these are simply phrased in the past tense). It is positively scored and has a minimum score of 0 (low) and a maximum score of 32 (high).

The Self-esteem subscale comprises six social self-esteem items and one performance self-esteem item from Heatherton and Polivy (1991). It includes items such as 'I feel self-conscious' and 'I feel inferior to others at the moment'. Items are negatively scored and the subscale has a minimum score of 0 (low) and a maximum score of 28 (high).

The Concentration subscale is made up of seven items, for example 'My attention is directed towards things other than the task' and 'My mind is wandering a great deal'. Items are negatively scored and the subscale has a minimum score of 0 (low) and a maximum score of 28 (high).

The Control and Confidence subscale comprises six items referring to how much in control the participant feels regarding the task. It includes items such as 'I feel confident about my abilities' and 'I feel as smart as others'. Items are positively scored and the subscale has a minimum score of 0 (low) and a maximum score of 24 (high).

Part 4, Thinking Content, comprises 16 items from Sarason *et al.*'s (1986) Cognitive Interference Questionnaire (CIQ) and measures the amount of interference

participants feel they have from thoughts relating to the task in hand, and from thoughts not relating to the task. The pre-task version requires participants to indicate how often they had had each thought during the last ten minutes, and the post-task version asks how often they had each thought whilst completing the task. All items are positively scored and rated on a 5-point Likert scale, with 1 being 'never' and 5 being 'very often'. The scale comprises two subscales. Task-related interference consists of eight items relating to thoughts about the task, for example 'I thought about how much time I had left' and 'I thought about the purpose of the experiment'. Task-irrelevant interference consists of eight items relating to thoughts not concerning the task, for example 'I thought about members of my family' and 'I thought about personal worries'. Each subscale has a minimum score of 8 (low interference) and a maximum score of 40 (high interference).

Item-based factor analyses discriminated ten of these dimensions as domain-specific factors (see Matthews *et al.*, 1999): the three main mood dimensions (EA, TA and HT; see section 3.3.1), the Motivation dimension and the six Cognitive dimensions. The final scales meet psychometric criteria for state measures, i.e. they have high internal consistency but lower test-retest reliability than traits (Zuckerman, 1976).

3.3.3 The State-Trait Anxiety Inventory (STAI: Spielberger, 1983)

The State-Trait Anxiety Inventory (STAI) provides a measure of how anxious an individual is at a particular given point (their State Anxiety) alongside how anxious they normally tend to be (their Trait Anxiety). Each of these questionnaires comprises 20 items rated on a 4-point Likert scale, with 1 being 'not at all' and 4 being 'very much so'. For the positively scored items, e.g. 'I feel upset' or 'I feel frightened', a score of 1

indicates the absence of anxiety and 4 indicates the presence of a high level of anxiety. For the negatively scored items, e.g. 'I feel calm' or 'I feel relaxed', a score of 1 indicates high anxiety and a score of 4 indicates no anxiety. The State Anxiety questionnaire includes ten positively scored items and ten negatively scored items, and the Trait Anxiety questionnaire includes 11 positively scored items and nine negatively scored items. Each has a minimum score of 20 and a maximum of 80. The State Anxiety questionnaire should be completed according to how the participant feels *at that particular moment*; the Trait Anxiety questionnaire should be completed according to how they *normally* feel.

Whilst many of the items have face validity as measures of 'anxiety', it is acknowledged that examiners should establish rapport with respondents in order to maximise the honesty of answers given; provided that sufficient care is taken in ensuring this, the distorting effects of adverse test-taking attitudes do not pose a serious problem (Spielberger, 1983). The reliability of the scale is demonstrated by the fact that the Trait Anxiety subscale is 'relatively impervious' to the conditions in which it is given (see Spielberger, 1983).

4. EMPIRICAL STUDIES

4.1 Circadian rhythm studies

4.1.1 Introduction to circadian rhythm studies

Circadian rhythm effects on mood have been well documented. The purpose of this subset of studies was to establish within- and between-subject variations in everyday mood, comparing different times of day to identify diurnal mood fluctuations. The first study examines sex differences as a preliminary consideration of the role of biological factors; the second study addresses diurnal mood changes in the context of the working day. These studies are a foundation for later research that brings in additional intrinsic and extrinsic variables to investigate the relationship between mood and biological rhythms.

4.1.2 Study 1: Time of day and sex differences in mood.

4.1.2.1 Introduction

Various studies have demonstrated circadian influences on mood, including diurnal mood variation and changes with circadian phase (see section 1.4.2). The aims of the present study were to broadly define where changes in mood occur in relation to time of day, and to identify sex differences and similarities as a starting point for focusing on women in subsequent studies.

Thayer (e.g. 2001) describes the typical pattern of mood variation throughout the day. In most individuals, mood is fairly low upon waking and increases gradually

throughout the morning, peaking late morning to early afternoon and reaching a low point mid afternoon, before increasing to a sub-peak early evening. Thayer also proposed that most moods result from combinations of energy and tension, with calm-energy almost always being a positive state and tense-tiredness always negative. Tense-energy and calm-tiredness may have positive or negative connotations depending on their context. For a more detailed review see section 1.2.1.

The diurnal mood patterns described have been applied to both males and females. It may be argued that when female participants are tested without taking the menstrual cycle into account, any menstrual cycle effects on mood (see section 1.3.4) will be cancelled out by participants being in different phases. Nonetheless, it is not just women who are subject to cyclical hormonal changes. Testosterone levels in men follow a circadian rhythm, tending to be highest in the morning and lowest in the evening (Kraemer *et al.*, 2001). It was therefore important to consider sex as a factor in the present study so that any differences could be taken into account in the design and interpretation of further research.

This study served as an initial pilot study to examine diurnal changes in different mood dimensions, as measured by the UWIST Mood Adjective Checklist (UMACL). The study compared subjective mood ratings across the day, with measurements taken in the morning, afternoon and evening. Based on Thayer's mood framework and 'typical' pattern, it was expected that:

1) Mood would be most positive in the morning, i.e. there would be higher levels of Energetic Arousal (EA) and Hedonic Tone (HT) and lower Tense Arousal (TA);

2) Mood would be least positive in the afternoon, i.e. lower levels of EA and HT and higher TA;

It was also anticipated that males and females would differ in their diurnal patterns of mood, although no direction of difference was specified.

4.1.2.2 Method

4.1.2.2.1 Participants

20 male (mean age = 24.70, s.d. = 7.23) and 20 female (mean age = 22.95, s.d. = 8.45) undergraduate students participated in the study. Participants were recruited via lectures and notice boards within the University.

4.1.2.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). The information sheet provided for participants is shown in Appendix B1.1; for the informed consent form see Appendix B1.2.

4.1.2.2.3 Procedure

Participants were given a booklet containing an information sheet, a consent form and three copies of the UMACL. Each UMACL had the participant's unique identification number written on it in case any of the sheets were detached. To ensure anonymity this number did not appear on the consent form, which was the only sheet to include the participant's name. Once completed this was detached from the booklet and returned

immediately before proceeding with the study. Consent forms were filed separately from the raw data.

Participants were instructed to complete a UMACL at approximately 10 a.m., 2 p.m. and 6 p.m. (within one hour either side of these times) on the same day. The questionnaires were labelled with the appropriate times. They were also asked to indicate their sex and age on the first questionnaire.

4.1.2.3 Results

Raw data can be found in Appendix C1, with full SPSS analysis in Appendix D1.

4.1.2.3.1 Time of day and sex effects on mood

Ratings on each subscale of the UMACL were entered into two-way, mixed design ANOVAs, with time of day (morning/afternoon/evening) as the within subjects factor and sex (male/female) as the between subjects factor. For full SPSS output, see Appendix D1.1.

For Energetic Arousal (EA) there was a significant main effect of time ($F_{2, 76} = 4.42$, $p = 0.015$). *Post hoc* paired *t*-tests with the Bonferroni correction revealed that only morning and afternoon EA differed significantly; neither a.m. nor p.m. EA differed from evening EA. There was no effect of sex ($F < 1$). There was, however, a significant interaction ($F_{2, 76} = 5.22$, $p = 0.01$). Simple effects analysis revealed that this was due to a selective decrease in evening EA in females ($p < 0.01$). Figure 1 illustrates this interaction: a.m. and p.m. EA scores were similar for males and females, but decreased in the evening for females only. All means and standard deviations can be found in Table 1a.

Table 1a: Means and standard deviations (in parentheses) for a.m., p.m. and evening Energetic Arousal scores in males and females.

	Mean Energetic Arousal score (min. = 8, max. = 32)		
	Morning	Afternoon	Evening
Males ($n = 20$)	18.90 (5.19)	22.00 (5.28)	22.50 (4.40)
Females ($n = 20$)	20.55 (4.72)	23.05 (4.87)	18.40 (3.95)
All ($N = 40$)	19.72 (4.97)	22.53 (5.04)	20.45 (4.62)
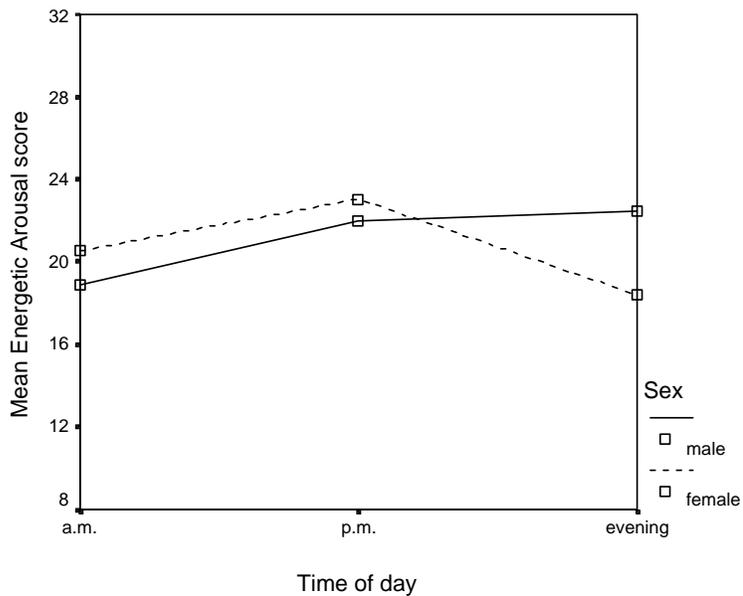
Figure 1: Interaction between time of day and sex on mean Energetic Arousal scores.

For Tense Arousal (TA) there was no effect of time ($F_{2, 76} = 1.75$, $p > 0.05$), no effect of sex ($F_{1, 38} = 1.80$, $p > 0.05$) and no interaction ($F_{2, 76} = 1.18$, $p > 0.05$). All means and standard deviations can be found in Table 1b.

Table 1b: Means and standard deviations (in parentheses) for a.m., p.m. and evening Tense Arousal scores in males and females.

	Mean Tense Arousal score (min. = 8, max. = 32)		
	Morning	Afternoon	Evening
Males (*n* = 20)	16.75 (5.20)	17.60 (4.88)	15.55 (4.59)
Females (*n* = 20)	15.75 (2.79)	14.75 (4.29)	14.60 (5.21)
All (*N* = 40)	16.25 (4.15)	16.17 (4.76)	15.08 (4.87)

For Hedonic Tone (HT) there was no effect of time ($F < 1$), no effect of sex ($F_{1, 38} = 1.87$, $p > 0.05$) and no interaction ($F_{2, 76} = 2.80$, $p > 0.05$). All means and standard deviations can be found in Table 1c.

Table 1c: Means and standard deviations (in parentheses) for a.m., p.m. and evening Hedonic Tone scores in males and females.

	Mean Hedonic Tone score (min. = 8, max. = 32)		
	Morning	Afternoon	Evening
Males (*n* = 20)	23.80 (5.64)	22.40 (6.92)	24.85 (7.00)
Females (*n* = 20)	25.50 (4.40)	26.70 (4.43)	25.30 (6.02)
All (*N* = 40)	24.65 (5.07)	24.55 (6.13)	25.07 (6.45)

To summarise, Energetic Arousal varied significantly across the day, peaking in the afternoon. Energetic Arousal showed a selective dip in the evening for females. There were no effects of either time of day or sex on Tense Arousal or Hedonic Tone.

4.1.2.3.2 Relationships between mood dimensions

Ratings on the Energetic Arousal (EA), Tense Arousal (TA) and Hedonic Tone (HT) subscales of the UMACL were entered into bivariate Pearson correlations. Each time of

day (morning, afternoon and evening) was analysed separately. $N = 40$ for all correlations. For full SPSS output, see Appendix D1.2.

EA was significantly and positively correlated with HT at all three time points (a.m.: $r = 0.62$, $p < 0.001$; p.m.: $r = 0.49$, $p = 0.001$; evening: $r = 0.33$, $p < 0.05$). TA was significantly and negatively correlated with HT at all three time points (a.m.: $r = -0.65$, $p < 0.001$; p.m.: $r = -0.82$, $p < 0.001$; evening: $r = -0.77$, $p < 0.001$). EA and TA were significantly and negatively correlated in the afternoon ($r = -0.35$, $p < 0.05$) and evening ($r = -0.31$, $p = 0.05$).

To summarise, increased Energetic Arousal corresponded to more positive mood across the day, namely increased Hedonic Tone. Conversely, increased Tense Arousal corresponded to more negative mood, namely decreased Hedonic Tone. Increased Energetic Arousal corresponded to decreased Tense Arousal in the afternoon and evening.

4.1.2.4 Discussion

Only Energetic Arousal (EA) showed overall diurnal variations, peaking in the afternoon. The fact that increased EA tended to correspond to decreased Tense Arousal and increased Hedonic Tone suggests that the increase in EA reflected a positive mood state, namely calm-energy (see Thayer, 2001). This contradicts Thayer's typical pattern of mood, which defines mid- to late afternoon as the point where mood is likely to be less positive.

One possible reason for this finding may relate to population characteristics. As Thayer points out there are deviations from the norm, with some individuals being

extreme 'morning' or 'evening' types. Whilst it is unlikely that most of the participants in this study were of one particular type, it is possible that as undergraduate students many of them would have adapted to becoming more alert later on in the day. Unlike much full-time employment, university study does not usually necessitate early morning attendance on a regular basis. The free-running circadian sleep-wake cycle in humans is approximately 25 hours, not 24 (see section 1.4.1), which indicates that we are adaptable to external cues; thus it is not unlikely that the 'typical' diurnal patterns of mood observed in most individuals are the result of learned rather than natural cycles.

An alternative explanation lies in the sex differences found in EA. Only females experienced a dip in evening energy ratings, with those of males staying fairly high - so it was only the female data that contradicted the expected trend of an evening sub-peak. In order for these to be menstrual cycle effects, a substantial proportion of the sample would need to be in a similar phase of the cycle.

In conclusion, this study provided useful information for defining positive and negative mood according to its different dimensions and raised questions concerning population and biological influences on diurnal mood rhythms.

4.1.3 Study 2: Pre- and post-class mood ratings in morning and afternoon student groups.

4.1.3.1 Introduction

Following on from Study 1, which demonstrated diurnal fluctuations for specific mood dimensions, the purpose of the present study was to examine these patterns in the context of the working day – specifically in an everyday, real-life setting where mood would be liable to change.

The abundance of literature on workplace stress (e.g. see Morris & Raabe, 2001) indicates a need to promote the management of mood within this environment. A full statement of the rationale underpinning this view can be found in section 1.1. The 'workplace', however, refers to a variety of situations and is not restricted to the supposedly typical 9-5 job. With more people of all ages choosing the option of full-time undergraduate study, it is important that they too are considered in this definition and related research – particularly as many undergraduates are also in part-time employment. One defining characteristic of undergraduate study is that it is relatively demanding in terms of required cognitive demand or effort. Increased cognitive effort has been associated with impaired affect (Fairclough *et al*, 2004), making this an important consideration in interpreting and managing everyday moods.

The present study was an applied piece of research that measured mood in a naturalistic and ecologically valid setting. As moods are highly influenced by external events (see section 1.2.1), circadian trends alone cannot account for changes throughout the day: however, they may alter the ways in which individuals respond to challenging circumstances. Participants in this study were undergraduate psychology students tested

during a workshop on research methods and statistics, held in either the morning or afternoon. This topic is known to cause anxiety among students (e.g. Onweugbuzie & Wilson, 2003). The detrimental effects of negative forms of arousal on performance (Yerkes & Dodson, 1908) mean that this would have implications for the efficacy of the workshop as well as students' psychological well-being. Considering Thayer's (e.g. 2001) mood framework, the results of Study 1 and the literature on statistics anxiety it was expected that:

1) Mood would be more negative (i.e. decreased Energetic Arousal and Hedonic Tone and increased Tense Arousal) following the research methods workshop;

2) The negative shift in mood would be exacerbated in participants tested in the afternoon.

4.1.3.2 Method

4.1.3.2.1 Participants

An opportunity sample of 28 undergraduate psychology students (4 male and 24 female) took part in the study. Ages ranged from 18 to 46 years (mean age = 22.29, s.d. = 7.45). Participants were tested at the start and at the end of a research methods workshop that ran regularly as part of their course; students attended either the morning or afternoon session for this workshop. The sessions ran on the same day and were identical. The benefits of maintaining this consistency in activities between the two groups was considered to outweigh the possible limitations of having time of day as a between-subjects factor.

4.1.3.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL). Participants gave their informed consent before taking part (see Appendix B2.1).

4.1.3.2.3 Procedure

The morning session ran from 10 a.m. to 1 p.m. and the afternoon session from 2 p.m. to 5 p.m. Participants were given a verbal briefing on the requirements of the study; they were told that mood would be measured at the start and end of their session, but were not made aware that the study was to investigate time of day effects on mood. The first UMACL was administered at the start of the workshop, and then collected immediately so that participants could not refer to their previous responses when completing the second. At the end of the workshop participants completed the UMACL again. Each UMACL had the participant's unique identification number written on it so that the two could be linked together. To ensure anonymity this number did not appear on the consent form, which was the only sheet to include the participant's name; this was administered and collected before proceeding with the study. Consent forms were filed separately from the raw data. Participants were debriefed on the true nature of the study in their sessions the following week.

4.1.3.3 Results

Raw data can be found in Appendix C2, with full SPSS analysis in Appendix D2. Ratings on each subscale of the UMACL were entered into 2 x 2 mixed design ANOVAs, with

test time (pre-/post-workshop) as the within-subjects factor and time of day (a.m./p.m.) as the between-subjects factor.

For Energetic Arousal (EA), there was no effect of test time ($F_{1, 26} = 2.58$, $p > 0.05$) and no effect of time of day ($F < 1$). There was, however, a significant interaction ($F_{1, 26} = 4.74$, $p < 0.05$). Simple effects analysis revealed that this was due to a selective reduction post-workshop in the afternoon group ($p = 0.01$). Figure 2 illustrates this interaction; EA scores before the workshop were equal for the morning and afternoon groups, yet the afternoon group experienced a drop in EA post-workshop. Means and standard deviations can be found in Table 2a.

Table 2a: Means and standard deviations (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) stratified by test time and time of day.

	Pre-workshop	Post-workshop
Morning ($n = 14$)	19.29 (5.97)	19.86 (6.66)
Afternoon ($n = 14$)	22.64 (5.20)	18.86 (4.19)
All ($N = 28$)	20.96 (5.75)	19.36 (5.48)
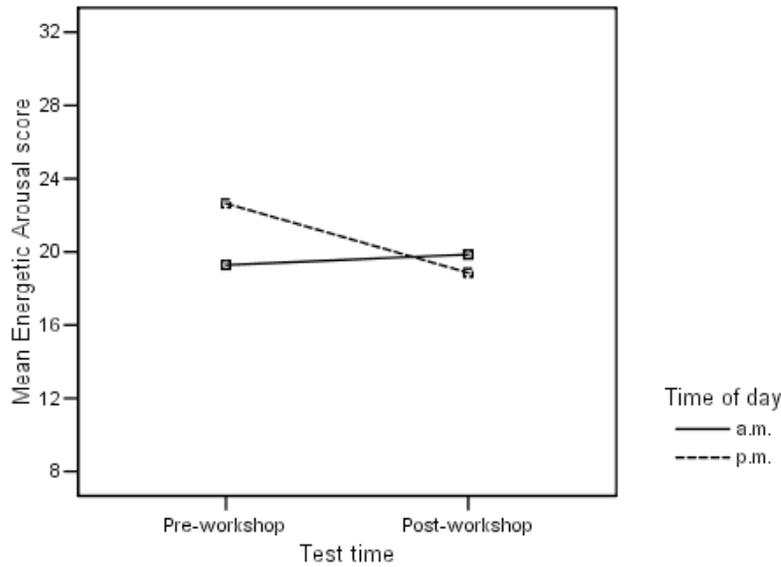
Figure 2: Interaction between test time and time of day on mean Energetic Arousal scores.

For Tense Arousal (TA), there was a significant main effect of test time ($F_{1, 26} = 18.68$, $p < 0.001$), with higher TA post-workshop. There was no effect of time of day ($F_{1, 26} = 2.50$, $p > 0.05$) and no interaction ($F_{1, 26} = 1.01$, $p > 0.05$). Means and standard deviations can be found in Table 2b.

Table 2b: Means and standard deviations (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) stratified by test time and time of day.

	Pre-workshop	Post-workshop
Morning ($n = 14$)	14.36 (4.09)	16.71 (5.94)
Afternoon ($n = 14$)	16.36 (4.38)	20.14 (5.05)
All ($N = 28$)	15.36 (4.28)	18.43 (5.69)

For Hedonic Tone (HT), there was a significant main effect of test time ($F_{1, 26} = 23.92$, $p < 0.001$), with lower HT post-workshop. There was also a significant main effect of time of day ($F_{1, 26} = 4.40$, $p < 0.05$), with lower HT in the afternoon group. There was no

interaction ($F_{1, 26} = 3.10$, $p > 0.05$). Means and standard deviations can be found in Table 2c.

Table 2c: Means and standard deviations (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) stratified by test time and time of day.

	Pre-workshop	Post-workshop
Morning ($n = 14$)	27.14 (3.80)	24.29 (5.33)
Afternoon ($n = 14$)	25.07 (5.90)	19.00 (5.64)
All ($N = 28$)	26.11 (4.98)	21.64 (6.02)

To summarise, mood was generally more negative and less positive following the research methods workshop, with increased levels of Tense Arousal and reduced Hedonic Tone post-workshop. Hedonic Tone was also generally lower in the afternoon group. The afternoon group experienced a selective reduction in Energetic Arousal post-workshop.

4.1.3.4 Discussion

The study findings revealed variations in mood as a function of test time (i.e. pre- or post-workshop), time of day and an interaction between the two factors. A negative shift in mood was observed following the research methods workshop, characterised by increased Tense Arousal (TA) and reduced Hedonic Tone (HT). Mood response to the workshop tended to be less positive in participants tested in the afternoon, as defined by decreased Energetic Arousal (EA). This fits the overall trend for less positive mood in the afternoon group, who generally demonstrated lower levels of HT than those tested in the morning. This afternoon 'dip' mirrors Thayer's (e.g. 2001) typical pattern of mood, as well as providing some support for the results of Study 1. Moreover, the findings suggest

that time of day not only affects mood itself, but also impacts upon the ability to cope with cognitive tasks.

The more negative mood observed in the afternoon fits the findings of Study 1, which found a selective decrease in EA in the evening for females only. Given that the afternoon and evening times in that study (2 p.m. and 6 p.m. respectively) approximate the timing of the afternoon session in the present study (2 p.m. to 5 p.m.), the results obtained here are not dissimilar – even with time of day as a between-subjects factor. It is interesting to note that the only general time of day effects were on TA and HT – the two dimensions apparently unaffected by the time of day in Study 1. However, the negative changes in post-workshop levels of EA at this time, combined with the high correlations between dimensions demonstrated by Study 1, suggests consistency between the two sets of results with regards to positive and negative shifts in the different mood dimensions. Subtle differences in responses to the different dimensions are expected given that mood is so highly influenced by its context.

Whilst the apparently impaired response to the workshop content in the afternoon is possibly due to diurnal changes in mood and arousal, it is also likely to also be a function of the cognitive demand involved in participating in the workshop itself, which involved research methods and statistics and was an important part of the undergraduate study programme. It has been postulated that up to 80% of psychology students experience 'statistics anxiety', one dimension of which is test and class-specific anxiety (Onweugbuzie & Wilson, 2003). This would imply that the cognitive demand required to process the material was high. The effects of increased cognitive demand on blood glucose levels and the affective costs of this process (see Fairclough *et al.*, 2004) may

help explain these findings; thus the possible role of blood glucose levels is investigated further in section 4.3, with a detailed review in section 1.2.

A further point to consider in interpreting these results relates to the characteristics of the sample. The majority of participants in this study, as with Study 1, were female. Yet in Study 1 the female results contradicted the expected diurnal trend in mood, whereas in this study the trends were similar to those observed for males previously. If the menstrual cycle is indeed a factor here, it would infer that the distribution of participants was fairly even across phases: any menstrual phase effects would have cancelled each other out this time to leave only normal diurnal effects. Alternatively, if the majority of participants were oral contraceptive users, which is not unlikely given the predominantly young age group, then this would in itself diminish any menstrual phase effects (see section 1.3.5). Thus the next series of studies addresses oral contraceptive use, as well as pursuing the suggested menstrual-circadian interaction (see section 4.2).

Although performance was not assessed during this study, there are still implications regarding the consequences of mood state for the learning of workshop material. The shifts in mood following the workshop, particularly in the afternoon, allude to a state of tense-tiredness – put forward by Thayer (e.g. 2001) as being an almost always negative state. As negative forms of arousal tend to impair performance (Yerkes & Dodson, 1908), students' ability to process the material might suffer as a result. Ironically, the negative arousal (i.e. increased TA in conjunction with reduced HT) appears to stem partly from the content of the workshop itself. This would produce a vicious circle in which it would be difficult to overcome the barriers associated with

learning this material. Subsequently, negative mood in response to the material itself and poor performance could, depending on its extent, even lead to the psychological well-being of the student being compromised. Despite the subject-specific nature of this particular study, it is easy to see how the same principle could apply to a range of cognitively demanding situations.

To conclude, this second study built upon the first to consider diurnal changes in mood in an applied setting, where mood state could not only be affected but also has potential consequences. The results give reason to consider the role of blood glucose levels and their interaction with biological rhythms.

4.1.4. Summary of circadian rhythm studies

This initial subset of studies is the first step in determining the complex relationship between biological rhythms, blood glucose and mood. The first study identified sex differences in circadian mood patterns, leading onto the study series in section 4.2, in which menstrual cycle effects on mood are considered alone and in relation to the time of day. The second study went on to consider diurnal mood trends in the context of the working day, revealing an exacerbation in negative mood response to cognitively demanding circumstances as a function of the time of day. The physiological processes underlying this phenomenon are addressed in the study series described in sections 4.3 and 4.4, which examine blood glucose levels in relation to cognitive task performance and biological rhythms. An important methodological consideration is the consistency of results with time of day as a within- and between-subjects factor. This demonstrates the

robustness of these effects and the appropriateness of classifying time of day as a between-subjects factor in future studies.

4.2 Menstrual cycle studies

4.2.1 Introduction to menstrual cycle studies

The idea that the menstrual cycle influences mood has become a universally accepted concept. This subset of studies examines both positive and negative variations in mood across the menstrual cycle, with the aim to recognise where mood is likely to be less positive. The first study was a pilot to establish cyclical changes in different mood dimensions, targeting specific days of the menstrual cycle to compare distinct phases. The second study was carried out to compare more broadly defined phases retrospectively, and also to determine the appropriateness of including menstrual cycle phase as a between-subjects factor in future studies. The final study in the series follows on from the first and brings in the circadian rhythm studies reported in section 4.1, considering time of day as a factor to address the possibility of a menstrual-circadian interaction.

4.2.2 Study 3: Mood ratings across the menstrual cycle.

4.2.2.1 Introduction

The 1980s and 1990s saw an explosion in the publication of menstrual cycle literature, with great emphasis on mood disturbance and the 'Premenstrual Syndrome' (see section 1.3.4 for a review). Moreover, many of the tools used to examine women's experiences of menstruation focused on its negative aspects. The present study was a pilot to examine menstrual cycle-related changes in different dimensions of mood, considering positive as well as negative fluctuations.

It is some consensus that mood tends to be at its most positive mid-cycle, around the time of ovulation (1.3.4). However, there is some conflict regarding mood and arousal changes in the premenstrual and menstrual phases. Various studies have found distress to be greatest at menstruation, which is consistent with reports of increased fatigue and decreased vigour at this time (e.g. Parlee, 1980; Cockerill, Wormington & Nevill, 1994). There is possibly a causal relationship between physical symptoms and negative mood symptoms during menstruation (Cockerill, Wormington & Nevill, 1994).

However, there is also evidence that the greatest mood disturbances occur in the few days prior to menstruation. Chaturvedi *et al.* (1995) found a significant increase in subjects reporting suicidal ideas during the premenstruum, supporting previous research (e.g. Stout *et al.*, 1986; Mandell & Mandell, 1967). Other symptoms, including irritability, mood swings, depression and water retention, were also reported more frequently in these women. Other studies have found disturbances in both the premenstrual and menstrual phases (Walker & Bancroft, 1990; Walker, 1994) compared with the ovulatory phase.

Physical and mood disturbances during the premenstrual and menstrual phases can be reduced by the use of oral contraceptives (e.g. Nilsson, Jacobson and Ingemanson, 1967; Moos, 1969; Rouse, 1978). This has been contradicted in more recent studies showing that premenstrual symptoms are unaffected, sometimes even aggravated, in oral contraceptive users (Bancroft & Rennie, 1993; Bancroft & Sartorius, 1990). This may be explained by the reduced dosages of hormones used in more modern oral contraceptives; nevertheless, their widespread use means that is important to consider any effects they might have (Richardson, 1992). Bancroft & Rennie (1993) found that triphasic pill users

tended to report more negative mood symptoms than those using the combined pill and non-users, which suggests that any effects that occur may be due to the types or levels of hormones they contain.

The present study compared mood at three points in the menstrual cycle: at the onset of menstruation, mid-cycle and premenstrually. Based on the studies outlined above it was hypothesised that mood would vary across these points but would be generally more positive mid-cycle, as defined by higher Energetic Arousal (EA) and Hedonic Tone (HT) and lower Tense Arousal (TA). Oral contraceptive use was also taken into account so that the study findings could be interpreted in the appropriate context.

4.2.2.2 Method

4.2.2.2.1 Participants

15 female undergraduate students aged 19-30 years (mean age = 20.80, s.d. = 3.47) participated in the study. Participants were recruited via lectures and notice boards within the University. 10 were oral contraceptive users and 5 had natural menstrual cycles. 87 % did not have children.

4.2.2.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). The information sheet provided for participants is shown in Appendix B3.1; for the informed consent form see Appendix B3.2. Participants also completed a menstrual questionnaire (see Appendix B3.3) containing questions on age, parity, contraception and date of last menstrual period. A

calendar sheet (see Appendix B3.4) was provided so that participants could identify the appropriate cycle days for completion of the UMACL.

4.2.2.2.3 Procedure

Participants were given an envelope containing an information sheet, consent form, a menstrual questionnaire, a calendar sheet, three copies of the UMACL and three stamped, addressed envelopes. Each UMACL and the menstrual questionnaire had the participant's unique identification number written on it so that the data could be linked together upon receipt. To ensure anonymity this number did not appear on the consent form, which was the only sheet to include the participant's name. Once completed this was returned immediately before proceeding with the study. Consent forms were filed separately from the raw data.

Participants were instructed to begin the study on the day of their next menstrual period onset (day 1 of the menstrual cycle) and to use the calendar sheet to identify days 15 and 25 of the cycle. Those using contraceptives that stopped them from menstruating, such as the contraceptive injection, were advised to use the first day of the month as day 1. On day 1 the first UMACL was completed and posted with the menstrual questionnaire. The following UMACLs were completed on days 15 and 25. Participants were asked to complete the UMACL at the same time on each day, or as close to this as possible, to avoid the possible confounding effects of time of day. All UMACLs were returned within 3 days of completion.

4.2.2.3 Results

Raw data can be found in Appendix C3, with full SPSS analysis in Appendix D3. The means and standard deviations for UMACL scores in the menstrual (day 1), mid-cycle (day 15) and premenstrual (day 25) phases are displayed in Table 3. Mood ratings for the menstrual, mid-cycle and premenstrual phases were compared using a one-way, within-subjects ANOVA, for each of the four subscales of the UMACL (Energetic Arousal, Tense Arousal, Hedonic Tone and General Arousal). Energetic Arousal (EA) varied significantly across the three phases ($F_{(2, 28}$ = 10.65, $p < 0.01$); *post hoc* paired *t*-tests with a Bonferroni correction revealed that menstrual EA was significantly lower than both midcycle and premenstrual ratings (see Table 3). There were no significant differences across phases in Tense Arousal (TA: $F_{(2, 28}$ = 2.32, $p > 0.05$) or Hedonic Tone (HT: $F_{(2, 28}$ = 2.89, $p > 0.05$). To summarise, only Energetic Arousal varied significantly across the menstrual cycle, reaching its lowest point during menstruation. Tense Arousal and Hedonic Tone did not differ between the menstrual, mid-cycle and premenstrual phases.

Table 3: Means and standard deviation (in parentheses) for UMACL scores across the menstrual cycle ($N = 15$).

	Menstrual	Midcycle	Premenstrual
Energetic Arousal (min.=8, max.= 32)	14.60 (2.85)	21.47 (5.71)	18.60 (5.14)
Tense Arousal (min.=8, max.= 32)	19.80 (5.97)	16.73 (6.66)	20.33 (6.04)
Hedonic Tone (min.=8, max.= 32)	19.20 (6.14)	24.13 (6.92)	20.67 (6.16)

4.2.2.4 Discussion

Only Energetic Arousal varied significantly across the menstrual cycle, reaching its lowest point in the menstrual phase. The results fit previous findings that positive mood and arousal are greater mid-cycle (Rossi & Rossi, 1977; Abplanalp, Donnelly & Rose, 1979; Cockerill, Wormington & Nevill, 1994). The significant change in Energetic Arousal, which was lowest on menstruation, is consistent with reports of increased fatigue and decreased vigour at this time (Aplanalp, Donnelly & Rose, 1977; Wilcoxon, Schraeder & Sherif, 1976; Parlee, 1980; Cockerill, Wormington & Nevill, 1994).

It should be noted that the group consisted mainly of oral contraceptive users. Furthermore, all of these were taking a form of combined pill. Triphasic contraceptive users tend to report more negative symptoms than either naturally cycling women or combined contraceptive users (see Bancroft & Rennie, 1993), which would explain the apparent subtlety of the mood changes demonstrated here; despite a pronounced menstrual dip in subjective energy, which corresponded to less positive ratings on the other mood dimensions, there were no marked cyclical differences in Tense Arousal or Hedonic Tone. This would suggest less positive rather than more negative mood. It should also be acknowledged that the menstrual phase in this study was defined as the onset of menses. Given the physical sensations that often accompany menstruation, particularly the first day or two (see section 1.3.3) it is perhaps not surprising that women feel less energetic at this time. Indeed, Cockerill et al (1994) proposed a causal relationship between physical symptoms and negative mood symptoms during menstruation.

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To conclude, this study confirms established findings of menstrual cycle-related fluctuations in mood, demonstrating that the UMACL is sensitive to these changes, but at the same time supports the notion that these mood disturbances are manageable rather than pathological.

4.2.3 Study 4: Within- and between-subject comparisons of perimenstrual and midcycle mood.

4.2.3.1 Introduction

Following Study 3, which demonstrated a decrease in subjective energy levels during menstruation, the present study sought to extend these findings. Unlike Study 3, in which participants recorded their mood as part of their own individual routines and according to specific cycle days, this study was conducted in a controlled setting to take 'snapshots' of moods at the beginning of a working day. By taking a measure of mood weekly for four subsequent weeks and taking a retrospective measure of menstrual cycle phase, participants' mood states were captured during the perimenstrual and midcycle phases. This method also enabled comparisons between participants tested at the same time in different phases. Based on the findings of Study 3, it was expected that:

1) Mood would be less positive, as defined by decreased Energetic Arousal and Hedonic Tone and increased Tense Arousal, during the perimenstruum compared with midcycle;

2) There would be consistency in within- and between-subjects effects.

Once more oral contraceptive use was considered as a potential factor.

4.2.3.2 Method

4.2.3.2.1 Participants

18 female undergraduate students aged 18 to 34 years (mean = 20.78, s.d. = 4.65) participated in the study. Participants were recruited via a research methods workshop, which they attended weekly at the same time each week. 5 were oral contraceptive users and 13 had natural menstrual cycles. 83% did not have any children.

4.2.3.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL). Following a verbal briefing on the nature and requirements of the study, participants completed an informed consent form (see Appendix B4.1). Participants also completed a menstrual questionnaire (see Appendix B4.2) containing questions on age, parity, contraception and date of last menstrual period (LMP), and a menses onset slip (see Appendix B4.3) to provide the date of their next menstrual period.

4.2.3.2.3 Procedure

Participants were given an envelope containing a consent form, a menstrual questionnaire, four copies of the UMACL and a menses onset slip. Each UMACL and the menstrual questionnaire and onset slip had the participant's unique identification number written on it so that the data could be linked together upon receipt. To ensure anonymity this number did not appear on the consent form, which was the only sheet to include the participant's name. Once completed this was returned immediately before proceeding with the study. Consent forms were filed separately from the raw data.

The workshop began at 10 a.m. each week. The first UMACL was completed at the start of the first session and returned with the consent form and menstrual questionnaire. Participants were instructed to bring their envelope with them for the following three sessions; at the start of each session the UMACL was completed and returned.

The LMP date was used to estimate whether each questionnaire was completed during the premenstrual to menstrual phase of the cycle (the perimenstruum) or during the midcycle. Menses onset was defined as day 1; based on a 28-day cycle, the premenstrual phase was defined as day 22 onwards, and the menstrual phase as days 1-7. All other days were defined as midcycle. This gave two measures for the perimenstruum and two measures for the midcycle for each participant. Participants were asked to provide the date of their subsequent menstrual period so that the phase defined by the date of their last period could be confirmed. This was done by simply writing the date on the menses onset slip and posting it in an envelope left outside the researcher's office. Participants had cycles of 22 to 36 days duration (mean = 29.11, s.d. = 3.86). In most cases the LMP date gave a reliable estimate of phase.

4.2.3.3 Results

Raw data can be found in Appendix C4, with full SPSS analysis in Appendix D4.

4.2.3.3.1 Analysis 1: Perimenstrual and midcycle mood (within-subjects; N = 17)

One participant did not complete the UMACL for all four weeks. Her data were therefore excluded from this analysis. Ratings on each subscale of the UMACL were analysed separately. For each participant, scores on each subscale were averaged over the two weeks in each phase to give a mean perimenstrual score (average of the premenstrual and menstrual weeks' scores) and a mean midcycle score (average of the two midcycle weeks' scores). Perimenstrual and midcycle averages were then entered into paired samples *t*-tests. For full SPSS output, see Appendix D4.1.

Significantly higher midcycle ratings were observed for Energetic Arousal (EA: $t_{16} = 2.60$, $p = 0.02$) and Hedonic Tone (HT: $t_{16} = 2.15$, $p < 0.05$). There were no significant differences between phases on Tense Arousal (TA: $t_{16} = 1.86$, $p > 0.05$). All means and standard deviations can be found in Table 4a. To summarise, mood was generally more positive midcycle compared to the perimenstruum, with increased Energetic Arousal and Hedonic Tone.

Table 4a: Means and standard deviation (in parentheses) for within-subject UMACL scores in the perimenstrual and midcycle phases ($N = 17$).

	Perimenstrual	Midcycle
Energetic Arousal (min.=8, max.= 32)	18.18 (2.75)	20.38 (4.00)
Tense Arousal (min.=8, max.= 32)	18.12 (2.61)	16.21 (3.67)
Hedonic Tone (min.=8, max.= 32)	23.09 (2.95)	25.03 (3.15)

4.2.3.3.2 Analysis 2: Perimenstrual and midcycle mood (between-subjects; N = 18)

Frequency counts for the number of participants in each phase in each week of the study revealed that weeks 2 and 4 contained very discrepant numbers, whereas weeks 1 and 3 were almost equal. The participant excluded from Analysis 1 had completed week 1, so her data were added to the dataset for this analysis so that there would be equal numbers of participants in each phase. Ratings for week 1 of the study for each subscale of the UMACL were entered into independent samples *t*-tests, comparing participants in the perimenstruum with those in the midcycle phase. For full SPSS output, see Appendix D4.2.

Significantly higher midcycle ratings were observed for Energetic Arousal (EA: $t_{16} = 2.19$, $p < 0.05$) and Hedonic Tone (HT: $t_{16} = 2.68$, $p < 0.02$). There were no significant differences between phases on Tense Arousal (TA: $t_{16} = 1.04$, $p > 0.05$). All means and standard deviations can be found in Table 4b. To summarise, mood was generally more positive midcycle compared to the perimenstruum, with increased Energetic Arousal and Hedonic Tone. The within-subjects effects found in Analysis 1 were replicated when menstrual cycle phase was grouped as a between-subjects factor.

Table 4b: Means and standard deviation (in parentheses) for between-subject UMACL scores in the perimenstrual and midcycle phases.

	Perimenstrual ($n = 9$)	Midcycle ($n = 9$)
Energetic Arousal (min.=8, max.= 32)	15.78 (3.73)	20.22 (4.82)
Tense Arousal (min.=8, max.= 32)	19.44 (3.97)	17.00 (5.85)
Hedonic Tone (min.=8, max.= 32)	19.78 (3.77)	25.22 (4.79)

4.2.3.4 Discussion

Mood within participants was found to be more positive midcycle compared with the perimenstrual weeks, characterised by higher subjective ratings of energy as measured by the Energetic Arousal (EA) subscale. These corresponded to higher midcycle ratings of Hedonic Tone (HT), which provides a measure of the overall pleasantness of mood and indicates that the mood shift demonstrated by increased EA was positive. These results were replicated in the second analysis, in which menstrual cycle phase was a between-subjects factor; this indicates that the effects were quite robust within the group and provides support for considering between-subjects phase effects in subsequent studies.

The cyclical changes in subjective energy support the findings of Study 3, which found that EA was lower in the menstrual phase. This study, however, also revealed an effect on HT. One explanation for this may relate to oral contraceptive use. The present study group consisted largely of naturally cycling women, as opposed to the majority in Study 3 being oral contraceptive users. HT has been linked to somatic comfort and physical feelings of well-being (see Morris *et al.*, 1998); the physical discomfort

experienced by many women around menstruation (see section 1.3.3) may explain why ratings on this dimension are less positive at this time. As Cockerill, Wormington & Neville (1994) point out, negative menstrual shifts in mood may be a function of physical symptoms. Oral contraceptives can help to alleviate these symptoms, which would explain why the participants in Study 3 did not experience mood shifts consistent with changes in bodily comfort.

Interestingly, the menstrual cycle-related changes in mood demonstrated in this study were manifested only in the positive dimensions of the UMACL; no effects were found on the more negative subscale of Tense Arousal (TA). This could arguably be interpreted as mood being more positive midcycle, instead of more negative perimenstrually. Again, there is support for the concept of maintaining positive mood across the menstrual cycle rather than attempting to 'cure' negative moods at certain points. On the other hand, this could be a function of the time at which testing took place. Studies 1 and 2 (see section 4.1) demonstrated that mood tended to be more negative in the afternoon; in the present study testing took place at 10 a.m., a time associated with more positive mood in the previous studies. The role of the time of day in menstrual cycle effects on mood is addressed in the next study.

To conclude, the findings of this study support and extend those of Study 3, indicating more positive mood in the middle of the menstrual cycle (i.e. around ovulation) than shortly before or during menstruation. The robustness of effects within and between participants suggests that it is appropriate to include cycle phase as a between-subjects factor in further studies.

4.2.4 Study 5: Menstrual cycle and circadian rhythm effects on mood.

4.2.4.1 Introduction

The studies so far have addressed circadian rhythm and menstrual cycle effects on mood separately (studies 1 & 2 and 3 & 4 respectively), demonstrating that mood tends to be less positive in the afternoon and around the time of menstruation. However, how these two factors might interact to affect mood has not yet been addressed. In other words, it is not known whether time of day effects on mood are consistent across menstrual cycle phases, and vice versa. Research indicating menstrual cycle-related changes in circadian temperature and melatonin rhythms, both of which are associated with mood (see section 1.5.4) gives reason to investigate such an interaction.

The present study used a 'diary' format to measure mood for 28 consecutive days so that an entire menstrual cycle would be captured, including time of day as a between-subjects factor. Based on the results of the studies reported so far, and existing evidence for a menstrual-circadian interaction, it was predicted that:

1) Mood would vary across the menstrual cycle and would generally be more positive mid-cycle, i.e. there would be greater Energetic Arousal (EA) and Hedonic Tone (HT) and lower Tense Arousal (TA) at this point;

2) Mood would vary across the day, with possibly more negative mood (i.e. lower EA and HT and higher TA) during the afternoon;

3) There would be an interaction between time of day and menstrual cycle phase;

4) Mood variations would be less pronounced in oral contraceptive users compared with naturally cycling women.

4.2.4.2 Method

4.2.4.2.1 Participants

51 female undergraduate students aged 18 to 45 years (mean = 22.02, s.d. = 6.28) participated in the study. 33 had natural menstrual cycles and 18 were oral contraceptive users. Naturally cycling women had not used any hormonal methods of contraception for at least three months prior to the study; similarly, oral contraceptive users had been using the same brand for at least three months. The two groups did not differ in terms of age (t_{49} = 0.62, p > 0.05). 86% of all participants had no children. The initial number of booklets distributed was approximately 100; once the exclusion criteria detailed in section 4.2.4.2.3 were applied, the final response/completion rate was approximately 1 in 2.

4.2.4.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL). Booklets were made up containing an information sheet (see Appendix B5.1), an informed consent form (see Appendix B5.2), a menstrual questionnaire (see Appendix B5.3) containing questions on age, parity, contraception and date of last menstrual period (LMP), and 28 copies of the UMACL. On the back of each UMACL was a diary sheet (see Appendix B5.4) so that participants could note whether they had started their period, were still menstruating, had taken a contraceptive pill, had changed their contraceptive method or had experienced any unusually stressful events that day. The booklets were colour-coded for different times of day.

4.2.4.2.3 Procedure

Participants were given the booklets to take away with them so that they could complete the questionnaires during the course of their normal day. Informed consent forms were completed during the briefing; once completed these were detached from the booklets and returned immediately before proceeding with the study. The consent forms were the only sheets containing participants' names; to ensure anonymity these were filed separately from the raw data.

Participants were instructed to begin the study as soon as was convenient, but to complete the UMACL and daily diary sheet within the same time range each day. Three different time slots were available: 9 a.m. to 10 a.m., 1 p.m. to 2 p.m. and 5 p.m. to 6 p.m. Participants were told that this was to ensure continuity and that the different times were available for their own convenience; they were not made aware that time of day would be included as a variable for analysis. They were asked to complete the mood scales over 28 consecutive days, and to simply leave any missed days blank. Each questionnaire also included a space so that the exact time of day could be recorded – participants were asked to be as consistent as possible but not to worry if they sometimes had to complete their questionnaires at other times.

Booklets were excluded from the analysis if they contained more than one blank questionnaire. One blank sheet was permitted provided that it did not occur on days 1, 8, 15 or 25 of the menstrual cycle (with the onset of menses defined as Day 1). For a blank sheet occurring on any other cycle day, mean scores across all other days substituted that day's scores on each mood dimension. Booklets were also excluded if there were substantial inconsistencies in the times of day they were completed, if a participant did

not menstruate during the course of the study, or if unusually stressful events were noted on days 1, 8, 15 and 25.

Cycle phase estimates were confirmed by LMP in most cases. The details given above (4.2.4.2.1) reflects the total number of participants after these exclusion criteria were applied ($N = 51$). On returning the booklets participants were fully debriefed on the true purpose of the study.

4.2.4.3 Results

Raw data can be found in Appendix C5, with full SPSS analysis in Appendix D5. For each of the following analyses, ratings on each subscale of the UMACL were analysed separately.

4.2.4.3.1 Analysis 1: 28-day trends in mood scores (all subjects; N = 51)

For each subscale of the UMACL, mean scores for each day 1-28 were calculated and curve estimations applied to determine quadratic trends across the menstrual cycle. For raw data see Appendix C5.1; for full SPSS output, see Appendix D5.1.

For Energetic Arousal (EA), there was a significant quadratic trend in scores across the menstrual cycle ($F_{25} = 8.73$, $p < 0.01$). Figure 3a illustrates this curvilinear relationship between EA and cycle day: EA scores were higher in the midcycle days compared with the earlier (menstrual) and later (premenstrual) stages of the cycle.
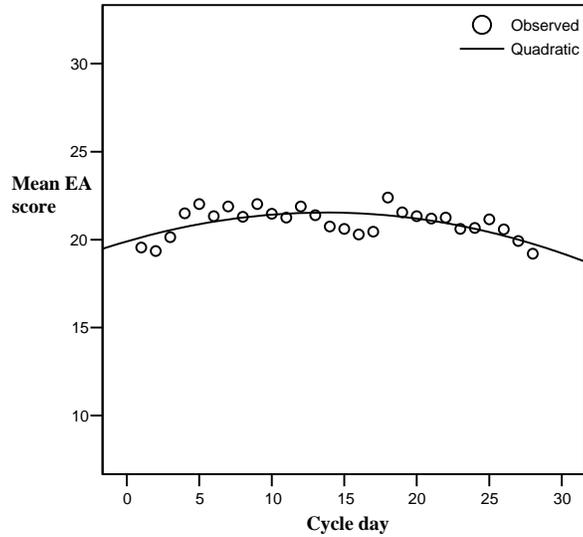
Figure 3a: Mean Energetic Arousal scores across the menstrual cycle.

For Tense Arousal (TA), there was a significant quadratic trend in scores across the menstrual cycle (F_{25} = 10.37, $p < 0.01$). Figure 3b illustrates this curvilinear relationship between TA and cycle day: TA scores were lower in the midcycle days compared with the earlier (menstrual) and later (premenstrual) stages of the cycle.
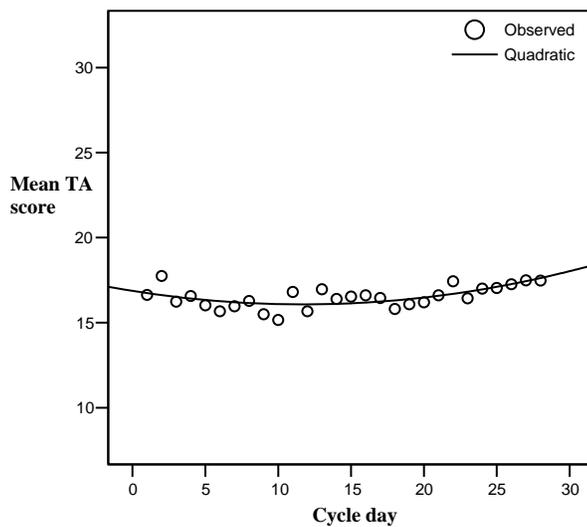
Figure 3b: Mean Tense Arousal scores across the menstrual cycle.

For Hedonic Tone (HT), there was no significant quadratic trend in scores across the menstrual cycle ($F_{25} = 2.11$, $p > 0.05$); see Figure 3c.
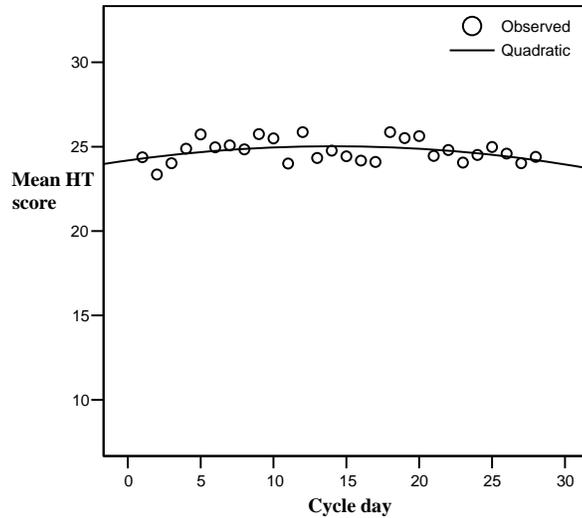
Figure 3c: Mean Hedonic Tone scores across the menstrual cycle.

To summarise, mood varied significantly across the 28 days of the menstrual cycle, with more positive mood (characterised by increased Energetic Arousal and reduced Tense Arousal) during the midcycle days compared with the menstrual and premenstrual days. Hedonic Tone did not vary across the menstrual cycle.

4.2.4.3.2 Analysis 2: Menstrual cycle phase and time of day (all subjects; N= 51)

Ratings on each subscale of the UMACL were entered into 4 x 3 mixed design ANOVAs, with menstrual cycle phase (menstrual, follicular, ovulatory and luteal) as the within-subjects factor and time of day (a.m., p.m. and evening) as the between-subjects factor. For raw data see Appendix C5.2; for full SPSS output, see Appendix D5.2.

For Energetic Arousal (EA), there was no effect of menstrual cycle phase ($F_{3, 144} = 1.790$, $p > 0.05$), no effect of time of day ($F_{2, 48} = 1.169$, $p > 0.05$), and no interaction ($F_{3, 144} = 1.464$, $p > 0.05$). Means and standard deviations can be found in Table 5a.

Table 5a: Means and standard deviations (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 17$)	19.29 (4.20)	19.94 (3.86)	19.76 (3.44)	21.18 (3.80)
1pm – 2pm ($n = 17$)	18.65 (4.87)	23.35 (4.34)	22.29 (4.44)	21.35 (5.15)
5pm – 6pm ($n = 17$)	20.71 (5.55)	20.59 (4.57)	19.76 (4.32)	20.94 (5.27)
All ($N = 51$)	19.55 (4.88)	21.29 (4.44)	20.61 (4.19)	21.16 (4.69)

For Tense Arousal (TA), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F < 1$), and no interaction ($F < 1$). Means and standard deviations can be found in Table 5b.

Table 5b: Means and standard deviations (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 17$)	17.35 (4.32)	16.12 (4.73)	16.41 (3.87)	17.47 (5.52)
1pm – 2pm ($n = 17$)	15.71 (4.25)	15.18 (5.00)	16.06 (4.21)	17.29 (6.00)
5pm – 6pm ($n = 17$)	16.82 (4.08)	17.53 (4.71)	17.12 (3.53)	16.35 (4.26)
All ($N = 51$)	16.63 (4.19)	16.27 (4.82)	16.53 (3.83)	17.04 (5.23)

For Hedonic Tone (HT), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F < 1$), and no interaction ($F_{3, 144} = 1.161$, $p > 0.05$). Means and standard deviations can be found in Table 5c.

Table 5c: Means and standard deviations (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 17$)	24.94 (4.02)	24.94 (5.24)	24.06 (5.55)	24.12 (5.28)
1pm – 2pm ($n = 17$)	23.76 (5.96)	26.35 (4.46)	26.00 (5.45)	25.00 (5.55)
5pm – 6pm ($n = 17$)	24.41 (5.72)	23.24 (4.15)	23.24 (4.15)	25.82 (3.83)
All ($N = 51$)	24.37 (5.22)	24.43 (5.12)	24.43 (5.12)	24.98 (4.89)

To summarise, neither menstrual cycle phase nor time of day were found to have an effect on Energetic Arousal, Tense Arousal or Hedonic Tone.

4.2.4.3.3 Analysis 3: Menstrual cycle phase, time of day and oral contraceptive use (all subjects; N= 36)

Data from Analysis 2 were grouped further to include oral contraceptive (OC) use as a factor. Due to the lower frequency of OC users compared to non-users, all of these were included and a random sample of non-users selected to provide equal sample sizes across cells. Ratings on each UMACL subscale were then entered into 4 x 3 x 2 mixed design ANOVAs, with menstrual cycle phase (menstrual, follicular, ovulatory and luteal) as the within-subjects factor. Time of day (a.m., p.m. and evening) and oral contraceptive use (yes/no) were the between-subjects factors. For raw data see Appendix C5.3; for full SPSS output, see Appendix D5.3.

For Energetic Arousal (EA), there was no effect of menstrual cycle phase ($F = 1$), no effect of time of day ($F_{2, 30} = 1.082$, $p > 0.05$), and no effect of OC use ($F < 1$). There was, however, a significant two-way interaction between menstrual cycle phase and OC use ($F_{3, 90} = 2.969$, $p < 0.05$; see Figure 4a). Simple effects analysis revealed that this

interaction was due to a selective decrease in EA in naturally cycling women in the menstrual phase ($p < 0.05$). There was also a significant three-way interaction between menstrual cycle phase, time and OC use ($F_{6, 90} = 2.165$, $p = 0.05$). Figure 4b illustrates this interaction. In OC users, EA was lower in the morning (9 a.m. to 10 a.m.) in the menstrual and follicular phases, and highest in the evening (5 p.m. to 6 p.m.) for all except the ovulatory phase. In non-users (naturally cycling women), EA was lowest in the afternoon (1 p.m. to 2 p.m.) during the menstrual phase, but highest in the afternoon in the follicular and ovulatory phases. Morning mood was higher than evening mood in the menstrual and luteal phases but equal in the follicular phase and lower in the ovulatory phase. There were no significant interactions between menstrual cycle phase and time of day ($F < 1$) or time of day and OC use ($F_{2, 30} = 2.736$, $p > 0.05$). All means and standard deviations can be found in Table 5d.

Table 5d: Means and standard deviations (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase, time of day and oral contraceptive use.

		Menstrual			Follicular	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	18.00 (3.74)	19.83 (3.97)	18.92 (3.80)	19.83 (3.82)	19.50 (3.73)	19.67 (3.60)
1pm - 2pm	22.17 (3.76)	15.83 (5.08)	19.00 (5.39)	21.00 (6.07)	24.50 (1.87)	22.75 (4.65)
5pm - 6pm	24.33 (5.85)	17.83 (3.92)	21.08 (5.84)	23.83 (4.12)	19.33 (4.59)	21.58 (4.78)
	21.50 (5.07)	17.83 (4.42)	19.67 (5.04)	21.56 (4.81)	21.11 (4.17)	21.33 (4.44)
		Ovulatory			Luteal	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	19.67 (4.27)	19.50 (2.59)	19.58 (3.37)	19.33 (3.78)	20.83 (3.60)	20.08 (3.61)
1pm - 2pm	19.50 (2.81)	23.33 (4.84)	21.42 (4.27)	19.50 (6.60)	20.33 (4.03)	19.92 (5.23)
5pm - 6pm	19.17 (4.75)	21.83 (3.71)	20.50 (3.96)	23.83 (7.11)	17.67 (3.08)	20.75 (6.14)
	19.44 (3.79)	21.56 (3.94)	20.50 (3.61)	20.89 (6.04)	19.61 (3.66)	20.25 (4.97)
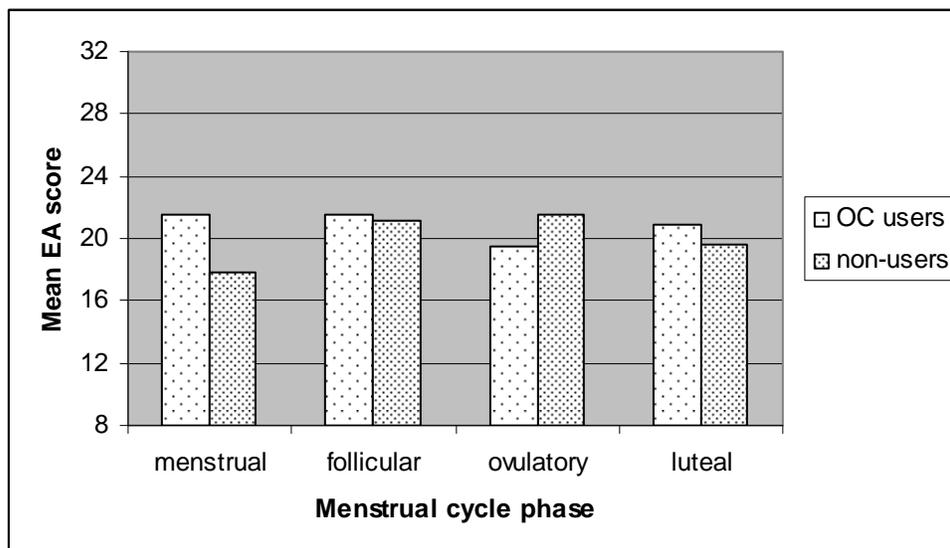
Figure 4a: Mean Energetic Arousal scores in oral contraceptive users and non-users: a 2-way interaction.
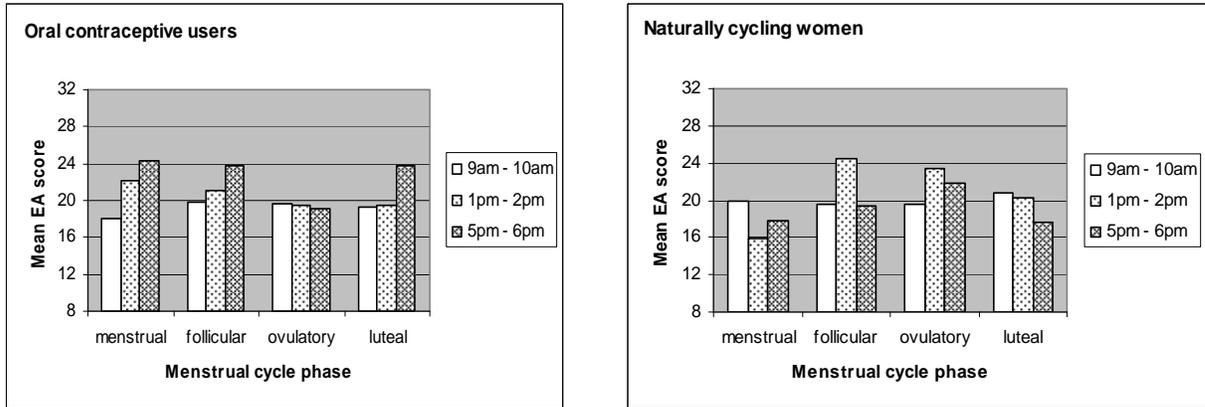
Figure 4b: Mean Energetic Arousal scores across the menstrual cycle and time of day for oral contraceptive users and non-users: a 3-way interaction.

For Tense Arousal (TA), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F < 1$), and no effect of OC use ($F < 1$). There were no significant interactions between menstrual cycle phase and time of day ($F < 1$), menstrual cycle phase and OC use ($F < 1$), or time of day and OC use ($F < 1$), and no significant three-way interaction between menstrual cycle phase, time of day and OC use ($F_{6, 90} = 1.002$, $p > 0.05$). Means and standard deviations can be found in Table 5e.

Table 5e: Means and standard deviations (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase, time of day and oral contraceptive use.

		Menstrual			Follicular	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	17.00 (4.38)	18.33 (4.89)	17.67 (4.48)	18.17 (4.02)	14.67 (2.34)	16.42 (3.63)
1pm - 2pm	16.67 (4.93)	15.67 (5.05)	16.17 (4.78)	14.33 (4.03)	16.50 (6.47)	15.42 (5.27)
5pm - 6pm	14.00 (2.68)	18.67 (4.23)	16.33 (4.16)	15.33 (4.72)	17.83 (5.27)	16.58 (4.94)
	15.89 (4.10)	17.56 (4.66)	16.72 (4.41)	15.94 (4.35)	16.33 (4.89)	16.14 (4.56)
		Ovulatory			Luteal	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	16.83 (3.06)	16.83 (4.26)	16.83 (3.54)	18.33 (4.32)	18.17 (7.00)	18.25 (5.55)
1pm - 2pm	17.00 (4.56)	16.33 (3.72)	16.67 (3.99)	16.83 (7.03)	19.00 (7.07)	17.92 (6.82)
5pm - 6pm	16.50 (2.81)	16.50 (3.89)	16.50 (3.23)	14.83 (3.87)	17.17 (4.58)	16.00 (4.22)
	16.78 (3.53)	16.56 (3.73)	16.67 (3.50)	16.67 (5.16)	18.11 (5.99)	17.39 (5.56)

For Hedonic Tone (HT), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F < 1$), and no effect of OC use ($F_{1, 30} = 2.121$, $p > 0.05$). There were no significant interactions between menstrual cycle phase and time of day ($F < 1$), menstrual cycle phase and OC use ($F_{3, 90} = 1.235$, $p > 0.05$), or time of day and OC use ($F_{2, 30} = 1.797$, $p > 0.05$), and no significant three-way interaction between menstrual cycle phase, time of day and OC use ($F < 1$). Means and standard deviations can be found in Table 5f.

Table 5f: Means and standard deviations (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) stratified by menstrual cycle phase, time of day and oral contraceptive use.

		Menstrual			Follicular	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	25.17 (3.43)	24.50 (3.89)	24.83 (3.51)	23.33 (7.15)	25.83 (3.43)	24.58 (5.50)
1pm - 2pm	25.17 (3.06)	22.83 (9.39)	24.00 (6.77)	25.33 (4.84)	26.67 (4.55)	26.00 (4.53)
5pm - 6pm	29.33 (2.81)	21.33 (4.84)	25.33 (5.63)	27.17 (3.76)	22.00 (6.60)	24.58 (5.79)
	26.56 (3.55)	22.89 (6.25)	24.72 (5.34)	25.28 (5.36)	24.83 (5.17)	25.06 (5.19)
		Ovulatory			Luteal	
	OC users	Non-users	All	OC users	Non-users	All
9am – 10am	24.17 (6.65)	23.50 (5.47)	23.83 (5.81)	25.17 (3.06)	21.83 (7.94)	23.50 (5.99)
1pm - 2pm	24.33 (4.63)	25.50 (7.06)	24.92 (5.73)	23.83 (6.08)	24.67 (6.44)	24.25 (5.99)
5pm - 6pm	24.33 (3.78)	24.33 (5.01)	24.33 (4.23)	28.00 (1.79)	23.00 (4.69)	25.50 (4.28)
	24.28 (4.85)	24.44 (5.62)	24.36 (5.17)	25.67 (4.22)	23.17 (6.21)	24.42 (5.39)

To summarise, the only effects present were on the Energetic Arousal subscale, with a decrease in the menstrual phase for naturally cycling women only and a three-way interaction between menstrual phase, time of day and oral contraceptive use. Neither Tense Arousal nor Hedonic Tone showed any significant menstrual cycle phase or time of day variations.

4.2.4.3.4 Analysis 4: Menstrual cycle phase and time of day – separate oral contraceptive use groups (N = 51)

The original dataset from Analysis 2 was split into two files so that oral contraceptive users and non-users could be analysed independently to examine the higher-order interaction found in Analysis 3. Ratings on each of the three subscales of the UMACL were then entered into 4 x 3 mixed design ANOVAs, with menstrual cycle phase (menstrual, follicular, ovulatory and luteal) as the within-subjects factor and time of day (a.m., p.m. and evening) as the between-subjects factor.

4.2.4.3.4.1: Menstrual cycle phase and time of day (naturally cycling women only; N = 33)

For raw data see Appendix C5.4.1; for full SPSS output, see Appendix D5.4.1. For Energetic Arousal (EA), there was a significant effect of menstrual cycle phase ($F_{3, 90}$ = 4.280, $p < 0.01$); *post hoc* paired *t*-tests with the Bonferroni correction revealed significantly lower EA in the menstrual phase. There was a significant effect of time of day ($F_{2, 30}$ = 4.076, $p < 0.05$); *post hoc* independent *t*-tests with the Bonferroni correction revealed significant differences between afternoon and evening ratings, with higher EA in the afternoon (1-2 p.m.). There was also a significant interaction ($F_{6, 90}$ = 3.281, $p < 0.01$). Figure 5 illustrates this interaction: simple effects analysis revealed significant menstrual cycle phase differences in the afternoon only ($p < 0.01$), with increased EA during the follicular and ovulatory phases at this time. All means and standard deviations can be found in Table 5g.

Table 5g: Means and standard deviations (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am (n = 11)	20.00 (4.43)	20.00 (4.07)	19.82 (3.13)	22.18 (3.57)
1pm – 2pm (n = 11)	16.73 (4.41)	24.64 (2.58)	23.82 (4.51)	22.36 (4.18)
5pm – 6pm (n = 11)	18.73 (4.47)	18.82 (3.89)	20.09 (4.28)	19.36 (3.38)
All (N = 33)	18.48 (4.51)	21.15 (4.30)	21.24 (4.31)	21.30 (3.87)
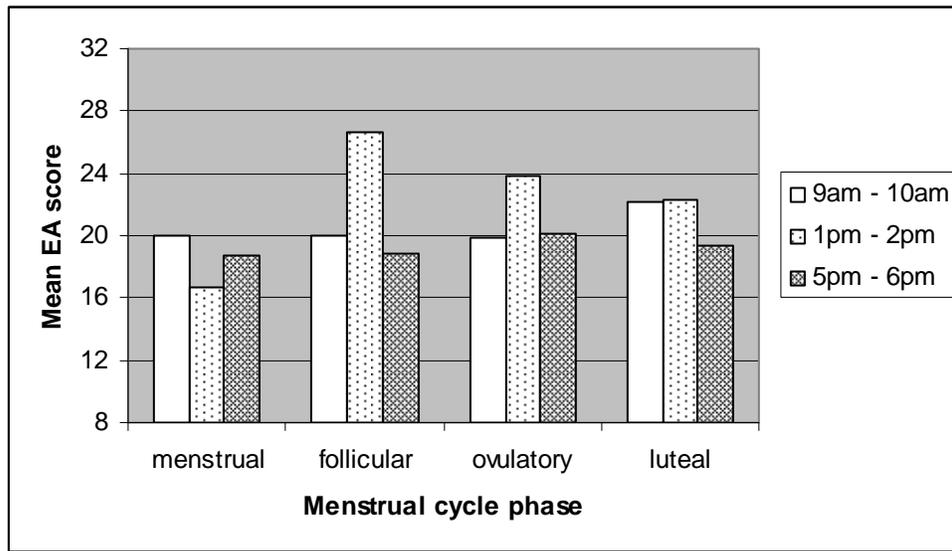
Figure 5: Interaction between menstrual cycle phase and time of day on mean Energetic Arousal scores.

For Tense Arousal (TA), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F_{2, 30}$ = 1.049, $p > 0.05$), and no interaction ($F < 1$). Means and standard deviations can be found in Table 5h.

Table 5h: Means and standard deviations (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am (*n* = 11)	17.55 (4.48)	15.00 (4.88)	16.18 (4.38)	17.00 (6.23)
1pm – 2pm (*n* = 11)	15.18 (4.00)	15.64 (5.59)	15.55 (4.13)	17.55 (5.72)
5pm – 6pm (*n* = 11)	18.36 (3.96)	18.73 (4.45)	17.45 (3.96)	17.18 (4.40)
All (*N* = 33)	17.03 (4.25)	16.45 (5.11)	16.39 (4.11)	17.24 (5.33)

For Hedonic Tone (HT), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F_{2, 30} = 2.659$, $p > 0.05$), and no interaction ($F_{6, 90} = 1.271$, $p > 0.05$). Means and standard deviations can be found in Table 5i.

Table 5i: Means and standard deviations (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am (*n* = 11)	24.82 (4.47)	25.82 (4.00)	24.00 (5.22)	23.55 (6.24)
1pm – 2pm (*n* = 11)	23.00 (7.10)	26.91 (4.37)	26.91 (5.86)	25.64 (5.43)
5pm – 6pm (*n* = 11)	21.73 (5.10)	21.09 (5.61)	22.64 (4.39)	24.64 (4.18)
All (*N* = 33)	23.18 (5.64)	24.61 (5.23)	24.52 (5.34)	24.61 (5.25)

To summarise, naturally cycling women experienced increased Energetic Arousal during the afternoon in the follicular and ovulatory phases. Tense Arousal and Hedonic Tone did not vary across the menstrual cycle or time of day.

4.2.4.3.4.2: Menstrual cycle phase and time of day (oral contraceptive users only; N = 18)

For raw data see Appendix C5.4.2; for full SPSS output, see Appendix D5.4.2. For Energetic Arousal (EA), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F_{2, 15} = 2.180$, $p > 0.05$), and no interaction ($F < 1$). Means and standard deviations can be found in Table 5j.

Table 5j: Means and standard deviations (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 6$)	18.00 (3.74)	19.83 (3.82)	19.67 (4.27)	19.33 (3.78)
1pm – 2pm ($n = 6$)	22.17 (3.76)	21.00 (6.07)	19.50 (2.81)	19.50 (6.60)
5pm – 6pm ($n = 6$)	24.33 (5.85)	23.83 (4.12)	19.17 (4.75)	23.83 (7.11)
All ($N = 18$)	21.50 (5.07)	21.56 (4.81)	19.44 (3.79)	20.89 (6.04)

For Tense Arousal (TA), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F < 1$), and no interaction ($F < 1$). Means and standard deviations can be found in Table 5k.

Table 5k: Means and standard deviations (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 6$)	17.00 (4.38)	18.17 (4.02)	16.83 (3.06)	18.33 (4.32)
1pm – 2pm ($n = 6$)	16.67 (4.93)	14.33 (4.03)	17.00 (4.56)	16.83 (7.03)
5pm – 6pm ($n = 6$)	14.00 (2.68)	15.33 (4.72)	16.50 (2.81)	14.83 (3.87)
All ($N = 18$)	15.89 (4.10)	15.94 (4.35)	16.78 (3.35)	16.67 (5.16)

For Hedonic Tone (HT), there was no effect of menstrual cycle phase ($F < 1$), no effect of time of day ($F_{2, 15} = 1.729$, $p > 0.05$), and no interaction ($F < 1$). Means and standard deviations can be found in Table 5l.

Table 5l: Means and standard deviations (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) stratified by menstrual cycle phase and time of day.

	Menstrual	Follicular	Ovulatory	Luteal
9am – 10am ($n = 6$)	25.17 (3.43)	23.33 (7.15)	24.17 (6.65)	25.17 (3.06)
1pm – 2pm ($n = 6$)	25.17 (3.06)	25.33 (4.84)	24.33 (4.63)	23.83 (6.08)
5pm – 6pm ($n = 6$)	29.33 (2.81)	27.17 (3.76)	24.33 (3.78)	28.00 (1.79)
All ($N = 18$)	26.56 (3.55)	25.28 (5.36)	24.28 (4.85)	25.67 (4.22)

To summarise, there were no menstrual cycle phase or time of day variations on any mood dimension for oral contraceptive users.

Summarising the results of all analyses for Study 5, initial analysis of trends across all days of the menstrual cycle indicated that some mood dimensions were generally more positive in the midcycle days, characterised by increased Energetic Arousal and decreased Tense Arousal compared with the days prior to and immediately following menstruation. When broken down to examine specific points in the menstrual cycle in relation to time of day, women with natural menstrual cycles demonstrated increased Energetic Arousal in the afternoon during the follicular and ovulatory (midcycle) phases only. By contrast, women taking oral contraceptives showed no mood variations at all.

4.2.4.4 Discussion

Among women with natural menstrual cycles, only Energetic Arousal (EA) was influenced by a menstrual-circadian interaction, with differences in afternoon mood according to cycle phase. Overall, EA was lower menstrually and higher in the afternoon; the nature of the interaction was to exacerbate these effects so that participants tested in the afternoon experienced a peak in EA during the midcycle (follicular and ovulatory phases). The midcycle peak in EA was not detected in those tested at other times of day. This finding was consistent with the preliminary analysis which indicated that mood was generally more positive in the midcycle days. Thus it appears that although the menstrual cycle may be responsible for some variation in mood, vulnerability to this variation is partly dependent on the time of day.

The findings support those of Studies 3 (4.2.2) and 4 (4.2.3) by demonstrating a dip in EA menstrually; unlike Study 4, however, there were no cycle phase effects on Hedonic Tone (HT) despite this being thought to relate to having a natural menstrual cycle. This is possibly due to situational factors: in Study 4 participants were tested in a workshop/classroom setting, which may have affected their HT by reducing or bringing attention to their somatic comfort at a time when they may be more sensitive to such feelings (i.e. around menstruation). Participants in the present study recorded their moods as part of their everyday routines, so may have been less susceptible to these effects.

It is important to acknowledge a potential flaw in this method of recording mood, in that participants would have been able to look back upon previous days when completing each day's UMACL. This could have resulted in biased responses according

to what participants believed was the intended purpose of the study. Alternatively, completion of the UMACL might have become routine to the point that participants no longer gave thought to their responses and simply circled the options habitually. Nevertheless, the selective nature of the observed effects suggests that this was not the case. Had the former scenario occurred one would expect effects on all of the mood dimensions; had the latter occurred then one would expect no cyclic effects at all.

Despite variations in effects upon the different mood dimensions across this study series, the most consistent patterns appear to be in EA, which is almost always affected. One possibility is that EA is a more pervasive mood state. Moods are highly variable and highly influenced by external events (see section 1.2.1), yet subjective energy levels may well differ as a result of the variables affecting them. Blood glucose is a major factor that contributes to mood state, and relates directly to feelings of energy. Given the findings of increased EA in the afternoon in the present study and in Study 1 (see section 4.1.2), it is quite possible that this is a function of lunch having been eaten at a particular time. The role of food and blood glucose levels is addressed in more depth in the next and subsequent study series (see sections 4.3 and 4.4).

It is perhaps surprising that oral contraceptive (OC) users experienced no time of day effects on mood. Whilst the elimination of menstrual symptoms is a common effect of OCs, given that they effectively abolish the menstrual cycle (see section 1.3.5), one would still expect circadian rhythm effects to be present – particularly considering that these have also been observed in men (see section 1.4.2). A possible explanation lies with blood glucose levels. Evidence for menstrual cycle-related changes in glycaemic control, along with conflicting findings regarding the effects that oral contraceptives have on this

process (see section 1.2.5), give reason to consider the possibility that blood glucose levels may be influenced by OC use and thus may contribute to differences in feelings of energy.

Interestingly, the changes in mood observed here were not particularly negative and tended to be more concerned with subjective energy and arousal than with tension, anger or the pleasantness of mood. Even where Tense Arousal (TA) was affected, one might argue that its cyclical trends reflected more positive mood mid-cycle rather than negative mood at other points. Again this fits the findings of Studies 3 and 4.

In conclusion, this study supports previous findings of menstrual cycle and circadian rhythm effects on mood, particularly subjective energy levels, and develops them further by suggesting that these effects may be enhanced by an interaction between the two factors. The study illustrates how women may be more vulnerable to shifts in mood at certain points, yet at the same time contradicts the negative view of the role of hormones in mood.

4.2.6 Summary of menstrual cycle studies

Throughout this series of studies as a whole, Energetic Arousal has been a recurring theme. The marked effect of menstruation on subjective energy, with less emphasis on tension, anger or the overall pleasantness of mood suggests that women are not victims of their 'raging hormones', but simply responding normally to natural physical changes. The absence of changes in oral contraceptive users suggests that these effects are genuinely related to the menstrual cycle, and also gives reason to examine the physiological

processes underlying mood in greater depth, leading on to study series 4.3 and 4.4. Again the subtle nature of mood is highlighted, and the role of context identified as crucial in the interpretation of menstrual mood changes and how these might be manifested. This subset of studies illustrates how women may be more vulnerable to shifts in mood at certain points in the menstrual cycle and that these may be exacerbated depending on the time of day; at the same time, it is important to emphasise that these changes are not necessarily negative. These studies have useful implications for the management of mood throughout the course of a typical day.

4.3 Blood glucose and cognitive task response studies

4.3.1 Introduction to blood glucose and cognitive task response studies

Blood glucose level is a major factor implicated in the regulation of mood. Furthermore, the impact of blood glucose levels on cognitive processes means that they may be instrumental in determining the way in which individuals respond to stressful situations, or those requiring increased cognitive effort. This subset of studies examines the relationship between blood glucose levels and mood, using glucose to directly manipulate blood glucose levels. The first study simply establishes the effects of raising blood glucose levels on different mood dimensions; the second study looks at the effects of ingesting glucose in the more specific context of mood and stress response to a cognitive task. The final study in this subset brings in time of day as an additional factor, aiming to clarify the physiology underlying the effects reported in previous sections.

4.3.2 Study 6: Effects of a glucose drink on mood at the beginning of the working day (for the published version of this paper please refer to Appendix A).

4.3.2.1 Introduction

Mood at the start of the working day is likely to be a major influence on ones' affective response to the rest of the working day. One factor that makes a substantial contribution to reported mood state is blood glucose level, with low blood glucose associated with increased tension and reduced arousal (see Thayer, 2001). This may be temporarily ameliorated by sugary snacks.

In healthy, young individuals blood glucose levels are maintained at approximately 5 mmol/l via a negative feedback loop (see section 1.2.2 for a detailed explanation of this process). Blood glucose levels fluctuate, following a diurnal rhythm, with higher levels observed during the morning compared with the afternoon (e.g. Troisi, Cowie & Harris, 2000). This corresponds to the typical pattern of mood variation throughout the day, as described by Thayer (1989; see also section 1.4.2). In most individuals, mood is less positive upon waking and improves gradually throughout the morning, peaking late morning and then becoming more negative in the afternoon. This suggests that mood begins to improve once blood glucose levels approach optimum concentration.

Previous research has indicated that increasing blood glucose levels has positive effects on mood, namely increased energy and reduced tension (Gold *et al.*, 1995; Benton & Owens, 1993; see section 1.2.3) Glucose ingestion has also been shown to have beneficial effects on cognitive performance, including improved recall of word lists (Benton and Sargent, 1992; Lapp, 1981) and increased listening span (Morris and Sarll, 2001). The latter study only found an improvement in students who had missed breakfast, indicating amelioration of the effects of low blood glucose levels resulting from fasting. This is of particular relevance to the present research, as many individuals start the day with blood glucose levels at the lower end of the range (Thayer, 2001).

This study examined the relationship between blood glucose and mood, addressing the possibility that increasing blood glucose levels by ingesting a glucose rich drink would have a positive effect on mood in the early part of the working day. Using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1) extended the range of

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mood dimensions measured by Benton and Owens (1993). The present study measured mood before and after the consumption of a glucose rich drink. Half of the participants imbibed a saccharine drink instead of the glucose drink to neutralise experimenter effects. It was predicted that mood would improve following the glucose drink, but not following the saccharine drink.

4.3.2.2 Method

4.3.2.2.1 Participants

6 male and 18 female participants, aged between 19 and 33 (mean age = 22.61, s.d. = 4.22), took part in this study as part of a research methods workshop. Diabetics, pregnant women and any individuals with serious medical conditions were excluded. All participants had eaten a light breakfast (roughly calculated to be < 500 kcal from the information given at the beginning of the study); none had fasted.

4.3.2.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). Following a verbal briefing on the nature and requirements of the study participants completed an informed consent form (Appendix B6.1) and a questionnaire that required them to itemise and quantify their breakfast that morning (Appendix B6.2).

Blood glucose level was tested using BM-Test 1-44 blood glucose test strips, following the manufacturer's procedure, then measured with a Prestige Medical Healthcare Ltd. HC1 digital Blood Glucometer. Each participant was provided with

written instructions for blood sampling, which included a table for the recording of readings (Appendix B6.3).

The glucose drink contained 50g glucose in 250ml of water plus 40ml sugar-free Robinson's 'Whole-orange squash' and 10ml of lemon juice (to reduce the sweetness). The saccharine ('placebo') drink was identical, except that 2g of 'Sweetex' replaced the glucose. A pilot study at the University of Wolverhampton indicated that students could not distinguish between the two drinks. All participants were told that they were drinking glucose *and* saccharine; this was so that if anyone needed to withdraw from the study because either drink would create medical problems they could do so without the precise experimental manipulation becoming apparent.

4.3.2.2.3 Procedure

Testing took place in a large teaching laboratory at the University of Wolverhampton, where participants were randomly assigned to either the glucose or saccharine group. They were not aware that there was a distinction. Baseline blood glucose levels were tested at 10 a.m.; participants tested their own blood glucose levels under strict supervision. Two blood samples were taken from each participant and the average of these two measures was used in the analysis.

The first UMACL was then administered; participants were then given either a glucose or saccharine drink and were requested to drink it rapidly. This was followed by an interval in which participants engaged in a research methods workshop. At the end of this interval, a second UMACL was administered and blood glucose tested again at approximately 12 p.m.

4.3.2.3 Results

Raw data can be found in Appendix C6, with full SPSS analysis in Appendix D6. The means and standard deviations for blood glucose readings and UMACL scores before and after the glucose and saccharine drinks are shown in Table 6. A two-way mixed design analysis of variance with Group (glucose/saccharine) as the between-subject factor and Test (before drink vs. after drink) as the within subject factor showed a significant effect of Group ($F_{1, 22} = 16.97$, $p < 0.01$) with higher blood glucose levels in the glucose group, a significant effect of Test ($F_{1, 22} = 23.93$, $p < 0.01$), showing that blood glucose levels were higher at second test and a significant interaction ($F_{1, 22} = 44.64$, $p < 0.01$). Simple effects analysis showed that the two groups did not differ in terms of blood glucose level at the beginning of the study but by the second testing the glucose groups' blood glucose level had significantly increased while the saccharine groups blood glucose readings remained unchanged ($p < 0.01$; see Figure 6).

Table 6: Means and standard deviation (in parentheses) for blood glucose levels (mmol/l) and UMACL scores before and after a glucose or saccharine drink.

	Glucose (*n* = 12)		Saccharine (*n* = 12)	
	Before drink	**After drink**	**Before drink**	**After drink**
Blood glucose (mmol/l)	5.21 (1.46)	7.93 (1.25)	5.18 (0.82)	4.75 (0.77)
Energetic Arousal (min. = 8, max. = 32)	18.58 (3.34)	23.08 (3.26)	19.42 (4.06)	20.92 (5.25)
Tense Arousal (min. = 8, max. = 32)	17.67 (4.05)	15.67 (3.47)	12.75 (2.53)	14.50 (3.37)
Hedonic Tone (min. = 8, max. = 32)	23.17 (5.11)	26.00 (4.45)	26.00 (3.19)	25.33 (3.63)
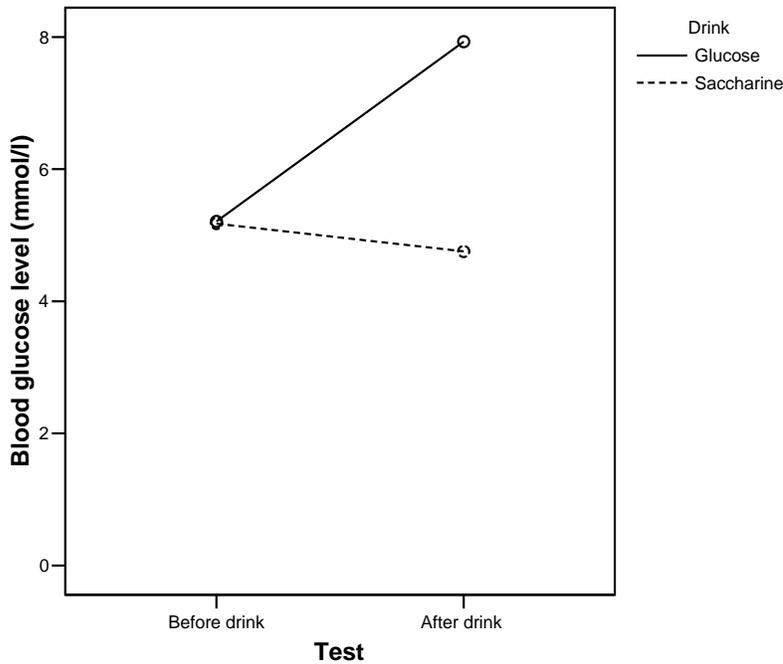
Figure 6: Interaction between test time (before vs. after drink) and type of drink (glucose vs. saccharine) on blood glucose levels.

As there were between-groups differences in baseline UMACL scores, the percentage by which each participant's score changed from before to after the drink was calculated for each of the three dimensions. Percent changes for the glucose and saccharine conditions were then analysed using independent samples t-tests. Percent change in Energetic Arousal was significantly greater for the glucose group ($t_{22} = 2.13$, $p < 0.05$), as was Tense Arousal ($t_{22} = 2.66$, $p < 0.02$), indicating in this instance a greater reduction in tension in the glucose group (see table 1). Percent change in Hedonic Tone was also significantly greater for the glucose group ($t_{22} = 2.29$, $p < 0.05$).

To summarise, both blood glucose levels and positive mood increased following a glucose drink but not following a saccharine drink.

4.3.2.4 Discussion

The results of the study showed that consuming a drink rich in glucose resulted in an increase in both blood glucose levels and positive mood. The findings support those of Benton and Owen (1995), who showed that higher blood glucose levels were linked to increased energy and reduced tension, and also those of Gold *et al.* (1995), which showed that it was possible to directly manipulate mood by altering blood glucose levels. Thus we replicate and contribute to the establishment of the reliability of these findings. However, the findings in this paper also extend these earlier findings by showing increases in hedonic tone. Elevated hedonic tone is associated with increased somatic comfort which is likely to be beneficial to work performance.

In conclusion, the results of the study indicate that raising blood glucose levels has immediately beneficial effects on mood at the start of the working day. This has practical applications within both professional and educational settings. However, one should interpret these findings with caution with regards to the extent and duration of these effects - as Thayer (1989) points out, 'sugar-snacking' can rebound as the initial energising and tension reducing effects can induce later fatigue and tension. Although positive mood may be enhanced rapidly, albeit temporarily, by using a convenient form of glucose to raise blood glucose levels, it would be inappropriate to recommend this as regular practice.

4.3.3 Study 7: Effects of a glucose drink on stress response to a recall task.

4.3.3.1 Introduction

As demonstrated by Study 6, positive mood may be enhanced by raising blood glucose levels and thus counteracting the detrimental effects of hypoglycaemia. When considered in relation to stress arising in the workplace, whether in an employment or educational context, it can be inferred that beginning with a calmer 'baseline' might buffer the effects of impending stressors (see Martino & Morris, 2004). This study looks directly at how individuals react to a cognitive task in terms of mood and stress, and how this response is influenced by blood glucose levels.

Study 2 indicated that mood tended to be negative following a research methods workshop. This effect might be explained by the cognitive demand, or mental effort required to participate in the workshop. Cognitive demand can be explained in terms of the mental effort required to complete a task; mental effort investment thus refers to energy mobilisation in the service of cognitive goals (Gaillard, 1993; 2001). Increased cognitive demand means greater mental effort investment: in other words, tasks that require greater mental effort, or have higher cognitive demand, necessitate increased energy mobilisation. This represents a compensatory strategy to 'protect' performance when task demands are augmented (Hockey, 1993; 1997). According to Mulder (1986) mental effort investment falls into two categories: 'task effort', which is a response to the computational demands of the task itself (e.g. time pressure, multi-tasking or high working memory load) and 'state effort', which is a response to non-task specific or environmental conditions (e.g. effects of fatigue, sleep deprivation or noise).

Yet it is important to consider the two-way nature of the relationship between mental effort investment and mental state. Whilst fatigue or tension may increase the mental effort investment required, the reverse may also be true – mental effort investment has psychological costs (Hockey, 1993; 1997). Fairclough *et al.* (2004) purport that the affective costs of increased mental effort investment may be the result of declining blood glucose levels. Increased cognitive demand has been found to accelerate the absorption of glucose from the bloodstream (Donohoe & Benton, 1999; Scholey et *al.*, 2001). Donohoe & Benton (1999) also found that individuals with high or stable blood glucose levels exhibited poorer cognitive performance, suggesting reduced uptake of glucose from the bloodstream. This corroborates evidence of improved cognitive performance resulting from the ingestion of glucose (see e.g. Morris, in press; Morris & Sarll, 2001; Benton & Sargent, 1992; Lapp, 1981). A more detailed review can be found in section 1.2.3.

The present study follows on from Studies 2 and 6 to consider the physiology underlying the apparent affective costs of cognitive processes. The mood-enhancing properties of glucose ingestion are examined in terms of response to a recall task, using the Dundee Stress State Questionnaire (DSSQ; section 3.3.2) to measure mood and stress response. This instrument was chosen as it includes the UWIST Mood Adjective Checklist (see section 3.3.1), which has been utilised throughout the present research, but also contains a number of other scales designed to specifically test response to cognitive tasks. The task itself utilises a video-based promotion designed to inform students about safety issues, a topic likely to be perceived as highly salient within the study sample (see Morris, in press). As with Study 6, half of the participants imbibed a saccharine instead of

a glucose drink to neutralise experimenter effects. Based on the literature on glucose and cognition and on the findings of Studies 2 and 6, it was expected that:

1) Recall would be improved following a glucose drink, but not a saccharine-based placebo;

2) Attitudes towards the recall task (stress state) would not differ between the two groups before performing it for the first time, but those ingesting glucose would report a more positive response to the task following the second test.

4.3.3.2 Method

4.3.3.2.1 Participants

4 male and 36 female undergraduate students, aged between 19 and 30 (mean age = 20.60, s.d. = 2.30), took part in this study as part of a research methods workshop. Diabetics, pregnant women and any individuals with serious medical conditions were excluded. All participants had eaten a light breakfast (roughly calculated to be < 500 kcal from the information given at the beginning of the study); none had fasted.

4.3.3.2.2 Materials

Stress state (including mood and cognitive state) was assessed using the Dundee Stress State Questionnaire (DSSQ; see section 3.3.2 for details of scoring and administration). Following a verbal briefing on the nature and requirements of the study, participants completed an informed consent form (Appendix B7.1) and a questionnaire that required them to itemise and quantify their breakfast that morning (Appendix B7.2). The equipment used for blood glucose testing and the glucose and saccharine drinks

administered were identical to those described in Study 6 above (see section 4.3.2.2.2). Each participant was provided with written instructions for blood sampling, which included a table for the recording of readings (Appendix B6.3).

Memory recall was assessed using a video on safety entitled 'A Sixth Sense: A Practical Guide to Your Personal Safety' (EagleEye Productions Video [2000] cat. No. EE9569), in which the content was summarised in a number of bulletin points at the end of each video. These videos were edited to produce two tapes, Tape A and Tape B. Tape A showed the 'Home' and 'Fieldwork' sections, which altogether lasted 9.5 minutes and contained 12 bulletin points. Tape B consisted of 'Out and About' and 'Public Transport', which altogether lasted 9 minutes and contained 17 bulletin points. Response sheets reproducing the outline of the video were provided for recall (see Appendix B7.4); these had the section headings and a line for each required response, but were otherwise blank. The experimenter scored the data by giving one point if a) a keyword was present in the response and b) the correct direction of the bulletin point was specified (e.g. correct distinction between 'do' and 'do not' advice in relation to the keyword). The order of viewing was counterbalanced so that half the participants viewed Tape A first (i.e. before the drink) and the other half viewed Tape B first. This was to eliminate any possible confounding effects of one tape being easier to recall than the other.

4.3.3.2.3 Procedure

Testing took place in a large teaching laboratory at the University of Wolverhampton, where participants were randomly assigned to either the glucose or saccharine group. They were not aware that there was a distinction. After completing a questionnaire that

required them to itemise and quantify their breakfast that day blood glucose levels were tested at 10 a.m. Participants tested their own blood glucose levels under strict supervision. Two blood samples were taken from each participant and the average of these two measures was used in the analysis.

The first DSSQ was then administered; participants were asked to complete it in relation to the recall task they were about to perform. The task was administered immediately afterwards; participants watched the video on overhead monitors situated at each workstation, slightly above eye level and approximately 2m distant. They were then given either a glucose or saccharine drink and were requested to drink it rapidly. This was followed by a 15-minute interval, in which they were asked not to consume any food or any drinks containing sugar. At the end of this interval, blood glucose was tested again at approximately 12 p.m., followed by the second recall task. Once this had been completed the second DSSQ was administered; participants were asked to complete it in relation to the task they had just performed.

4.3.3.3 Results

Raw data can be found in Appendix C7, with full SPSS analysis in Appendix D7. Blood glucose readings and recall were entered into two-way, mixed design analyses of variance (ANOVA), with Test (before drink vs. after drink) as the within-subjects factor and Group (glucose/saccharine) as the between-subjects factor. The means and standard deviations for blood glucose readings and recall scores before and after the glucose and saccharine drinks are shown in Table 7a.

For blood glucose there was a significant main effect of Test ($F_{1, 38} = 72.79$, $p < 0.001$), with higher blood glucose levels after the task, and a significant main effect of Group ($F_{1, 38} = 28.35$, $p < 0.001$), with higher blood glucose levels in the glucose group. There was also a significant interaction ($F_{1, 38} = 50.79$, $p < 0.001$); simple effects analysis revealed that blood glucose levels did not differ between the two groups on the first test, but on the second test the glucose group's blood glucose level had significantly increased while the saccharine group's blood glucose readings remained unchanged ($p < 0.01$; see Figure 7).

For recall there was a significant main effect of Test ($F_{1, 38} = 10.82$, $p < 0.01$), with increased recall on the second test. There was no effect of Group ($F_{1, 38} = 2.24$, $p > 0.05$) and no interaction ($F_{1, 38} = 1.28$, $p > 0.05$). Thus recall was increased on the second test irrespective of the drink consumed.

Table 7a: Means and standard deviation (in parentheses) for blood glucose levels (mmol/l) and memory recall (%) before and after a glucose or saccharine drink.

	Glucose ($n = 20$)		Saccharine ($n = 20$)	
	Before drink	**After drink**	**Before drink**	**After drink**
Blood glucose (mmol/l)	4.62 (0.88)	7.35 (1.47)	4.42 (0.84)	4.67 (0.71)
Recall (%)	53.08 (17.89)	66.42 (15.40)	48.82 (20.38)	55.33 (21.07)
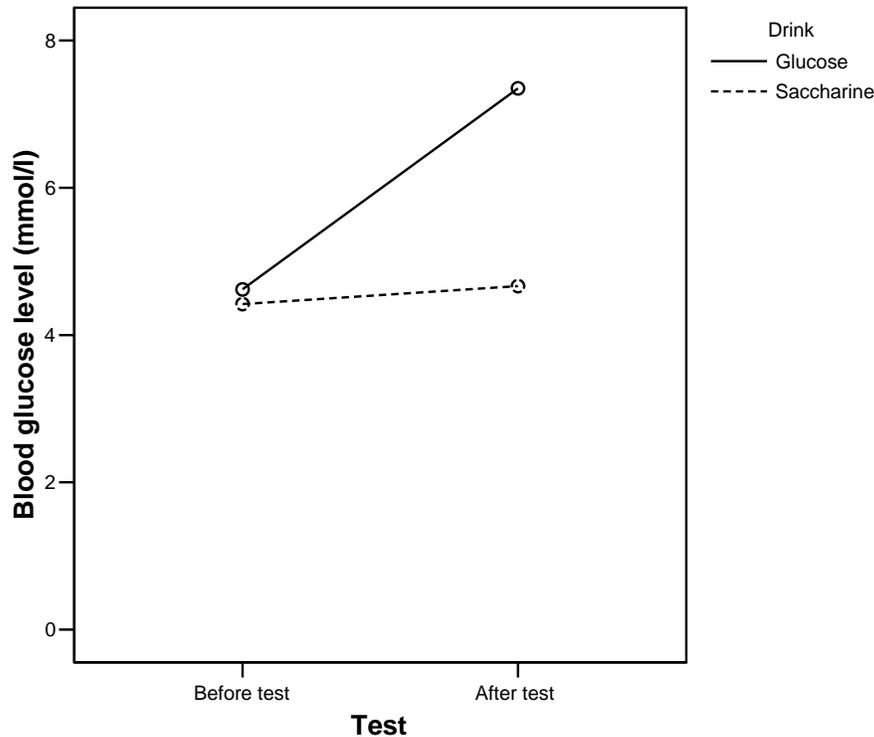
Figure 7: Interaction between test time (before vs. after drink) and type of drink (glucose vs. saccharine) on blood glucose levels.

As the DSSQ was completed before the first recall task and after the second, it was not deemed appropriate to compare the two sets of scores as they did not refer to the same task. Instead two sets of analyses were conducted: firstly a series of *t*-tests was performed to compare baseline scores between groups on the various dimensions, to ensure that the glucose and saccharine groups did not differ at the beginning of the study. A second series of *t*-tests was then performed to determine any between-groups differences in how they felt whilst completing the second task. All means and standard deviations can be found in Table 7b.

There were no baseline differences between the glucose and saccharine groups on Energetic Arousal ($t_{38} = 0.54$, $p > 0.05$), Tense Arousal ($t_{38} = 0.64$, $p > 0.05$), Hedonic Tone ($t_{38} = 1.39$, $p > 0.05$), Motivation ($t_{38} = 1.56$, $p > 0.05$), Self-Focused Attention ($t_{38} = 1.13$, $p > 0.05$), Self-Esteem ($t_{38} = 0.11$, $p > 0.05$), Concentration ($t_{38} = 0.41$, $p > 0.05$), Control & Confidence ($t_{38} = 1.67$, $p > 0.05$), Task-Related Interference ($t_{38} = 0.39$, $p > 0.05$) or Task-Irrelevant Interference ($t_{38} = 1.15$, $p > 0.05$).

Whilst completing the second task the glucose group experienced significantly lower Tense Arousal ($t_{38} = 2.44$, $p < 0.025$), Self-Focused Attention ($t_{38} = 2.80$, $p < 0.01$), Task-Related Interference ($t_{38} = 2.15$, $p < 0.05$) and Task-Irrelevant Interference ($t_{38} = 2.15$, $p < 0.05$) compared with the saccharine group. The glucose group also reported significantly higher Hedonic Tone ($t_{38} = 2.05$, $p < 0.05$) and Concentration ($t_{38} = 3.00$, $p < 0.01$). There were no differences between groups on Energetic Arousal ($t_{38} = 0.61$, $p > 0.05$), Motivation ($t_{38} = 0.14$, $p > 0.05$), Self-Esteem ($t_{38} = 1.56$, $p > 0.05$), Control & Confidence ($t_{38} = 0.95$, $p > 0.05$) or Workload ($t_{38} = 0.99$, $p > 0.05$).

Table 7b: Means and standard deviation (in parentheses) for baseline DSSQ scores and scores following a recall task, having consumed a glucose or saccharine drink.

	Baseline		End test	
	Glucose **(_n_ = 20)**	**Saccharine** **(_n_ = 20)**	**Glucose** **(_n_ = 20)**	**Saccharine** **(_n_ = 20)**
Energetic Arousal (min. = 8, max. = 32)	18.20 (4.84)	19.00 (4.48)	21.50 (4.07)	20.75 (3.67)
Tense Arousal (min. = 8, max. = 32)	17.25 (4.89)	18.25 (4.96)	14.55 (4.17)	17.65 (3.86)
Hedonic Tone (min. = 8, max. = 32)	24.95 (3.83)	23.10 (4.56)	25.65 (3.51)	23.10 (4.30)
Motivation (min. = 0, max. = 72)	42.15 (9.03)	46.80 (9.82)	39.10 (7.87)	38.70 (10.64)
Self-Focused Attention (min. = 0, max. = 32)	9.60 (6.41)	11.85 (6.19)	3.00 (3.11)	7.55 (6.57)
Self Esteem (min. = 0, max. = 28)	17.75 (7.09)	17.50 (7.02)	24.15 (4.93)	20.95 (7.72)
Concentration (min. = 0, max. = 28)	21.05 (6.14)	20.25 (6.13)	24.50 (3.93)	19.40 (6.51)
Control & Confidence (min. = 0, max. = 24)	14.25 (3.13)	11.95 (5.33)	14.60 (5.48)	12.85 (6.12)
Task-Related Interference (min. = 8, max. = 8)	16.85 (4.86)	17.55 (6.72)	13.60 (4.99)	17.50 (6.40)
Task-Irrelevant Interference (min. = 8, max. = 40)	14.65 (5.45)	16.90 (6.82)	11.30 (3.42)	14.80 (6.45)
Workload (min. = 0, max. = 60)	N/A	N/A	24.95 (7.26)	27.35 (8.12)

To summarise, blood glucose levels were significantly raised by ingesting a glucose drink, but not a saccharine drink. Memory recall was significantly higher on the second test irrespective of the drink consumed. The two groups did not differ in baseline scores on any dimension of the DSSQ at the start of the study. However, those who had ingested glucose experienced significantly lower Tense Arousal, Self-Focused Attention, Task-Related Interference and Task-Irrelevant Interference, and significantly higher Hedonic Tone and Concentration whilst completing the task for the second time compared to those who had ingested saccharine. Whilst raising blood glucose levels did not facilitate recall, it reduced stress response to the task.

4.3.3.4 Discussion

Despite significantly increased blood glucose levels following the glucose drink but not the saccharine placebo, drinking glucose did not significantly improve recall. Recall of bulletin points from the safety video was significantly higher after the drink, but because this occurred irrespective of the drink consumed it could not be inferred that raised blood glucose level was the cause of this improvement. A practice effect may well have been demonstrated.

The interesting finding, however, was that even without improving performance, drinking glucose significantly improved stress response to the recall task. The glucose group reported lower tension and less interference, as well as higher concentration and more pleasant mood (as indicated by the Hedonic Tone subscale) whilst performing the task for the second time compared to those who imbibed saccharine. Thus the saccharine group were clearly disadvantaged by the lack of glucose available, yet managed to

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maintain a performance level comparable to those who had consumed glucose. It is possible that this reflects the compensatory strategy proposed by Hockey (1993; 1997); the higher stress response in the saccharine group may represent the affective costs of increased mental effort investment resulting from reduced glucose availability (see Fairclough *et al.*, 2004). The second DSSQ provided a measure of how participants felt whilst actually completing the task, therefore they may have even been making a conscious effort to compensate in their performance.

Whether the result of conscious over-compensation or automatic adaptation, these affective costs are an important consideration in preventing stress in the workplace. Although the results suggest that individuals are able to adapt to less than ideal physiological conditions to maintain performance levels, it is evident that the effects of reduced glucose availability may manifest themselves in other ways. Prolonged exposure to such a state could potentially lead to increased or even pathological levels of stress, which in the long term will inevitably result in impaired performance.

4.3.4 Study 8: Effects of a glucose drink on mood and anxiety response to the Stroop task.

4.3.4.1 Introduction

Study 7 demonstrated beneficial effects of glucose ingestion on stress response to a cognitive task, even when performance on the task was not affected. This study looks specifically at anxiety alongside mood, considering the role of trait anxiety in an individual's response to a cognitively demanding task with and without the aid of

glucose. The study builds on the circadian rhythm and blood glucose studies reported previously, bringing in time of day to elaborate on and bring together Studies 2, 6 and 7.

Blood glucose levels fluctuate, following a diurnal rhythm, with higher levels observed during the morning compared with the afternoon (e.g. Troisi, Cowie & Harris, 2000). This corresponds to the typical pattern of mood variation throughout the day (Thayer, 1989; see also section 1.4.2). The circadian blood glucose rhythm may provide some explanation for why the negative mood response to a research methods workshop (Study 2) was more pronounced among participants tested in the afternoon. Furthermore, anxiety was thought to play a part in the negative response to the workshop content.

The present study examines the role of anxiety in response to a task requiring cognitive effort. The study utilised the Stroop colour-word interference task (Stroop, 1959), which has been shown to require cognitive effort and induce anxiety (Šiška, 2002). Mood was measured using the UWIST Mood Adjective Checklist (UMACL) and anxiety using the Spielberger State-Trait Anxiety Inventory (STAI; see section 3.3.3). Based on the literature on blood glucose, mood and cognition, and on the findings of Studies 2, 6 and 7 it was predicted that:

1) Blood glucose levels would be higher in the morning, but would be significantly raised following a glucose drink (but not a saccharine drink) regardless of the time of day;

2) Performance on the Stroop task would be better among participants consuming glucose compared with those consuming saccharine;

3) The glucose group would display more positive mood, defined by higher Energetic Arousal (EA) and Hedonic Tone (HT) and lower Tense Arousal (TA), and lower state anxiety following the task compared with the saccharine group;

4) Mood would generally be less positive (i.e. lower EA and HT and higher TA) and state anxiety higher among participants tested in the afternoon.

5) Mood would generally be less positive and state anxiety higher following the task; these effects would be exacerbated among participants tested in the afternoon;

6) Participants with higher trait anxiety would exhibit a more negative response to the task in terms of mood and state anxiety.

It was also anticipated that the type of drink and the time of day would interact to influence response to the task, i.e. the effects of glucose would be enhanced in the morning compared with the afternoon.

4.3.4.2 Method

4.3.4.2.1 Participants

7 male and 25 female undergraduate students, aged between 18 and 39 (mean age = 22.53, s.d. = 5.63), took part in this study. Participants were recruited via lectures and University notice boards. Diabetics, pregnant women and any individuals with serious medical conditions were excluded. The vast majority of participants had eaten breakfast or lunch prior to participating in the study.

4.3.4.2.2 Materials

All participants were required to read through an information sheet detailing the nature and content of the study (Appendix B8.1) and complete an informed consent form (Appendix B8.2) before taking part. Mood was measured using the UWIST Mood Adjective Checklist (UMACL); State and trait anxiety were measured using the State-Trait Anxiety Inventory (STAI; see section 3.3.3 for details of scoring and administration). The equipment used for blood glucose testing and the glucose and saccharine drinks administered were identical to those described in the Materials section of Study 7 above.

The Stroop task consisted of six laminated, white A4 sheets printed with colour names (black, red, blue and yellow) in conflicting colours, e.g. the word 'red' printed in black. Each sheet contained 30 or 31 colour names (with a total of 185) printed in Times New Roman 36pt. font. Colour names could appear in any colour but their own, e.g. 'red' could appear in black, blue or yellow but never in red. The participant's task was to name the ink colour and not read out the word. They were timed using a stopwatch and taped using a cassette recorder. Correct responses were checked whilst the task was being completed against a pre-prepared checklist (see Appendix B8.3).

4.3.4.2.3 Procedure

Participants were tested individually in an experimental cubicle at the University of Wolverhampton. Upon arrival the first blood glucose reading was taken; participants tested their own blood glucose levels under strict supervision. Two blood samples were

taken from each participant and the average of these two measures was used in the analysis.

The first STAI and UMACL were then administered. The time of day and whether or not breakfast or lunch had been eaten prior to attending the session was noted at the top of the first questionnaire. This was also marked to indicate which drink condition the participant had been assigned to, but participants were not aware of this – all participants were informed that the drink they were about to consume contained glucose. The participant was then given either a glucose or saccharine drink and requested to drink it rapidly; this was followed by a 10-minute interval in which they were instructed not to consume any food or any drinks containing sugar.

Upon returning the participant's blood glucose levels were tested again, followed immediately by the Stroop task, which took approximately 5 minutes to complete. Following the Stroop task the second STAI and UMACL were administered. At the end of the study the participant was debriefed and, where applicable, made aware that the drink they had consumed did not contain glucose.

4.3.4.3 Results

Raw data can be found in Appendix C8, with full SPSS analysis in Appendix D8.

4.3.4.3.1 Analysis 1: Type of drink and time of day

Blood glucose levels, UMACL and STAI State scores were entered into three-way, mixed design analyses of variance (ANOVA), with Test (before task vs. after task) as the within-subjects factor. The between-subjects factors were Group (glucose/saccharine)

and Time of day (morning/afternoon). Means and standard deviations are in Table 8a. For full SPSS output, see Appendix D8.1.

For blood glucose there was a significant main effect of Test ($F_{1, 28} = 37.61$, $p < 0.001$), with higher blood glucose levels after the task, a significant main effect of Group ($F_{1 40} = 34.04$, $p = 0.01$), with higher blood glucose levels in the glucose group, and a significant main effect of Time of day ($F_{1, 28} = 4.90$, $p < 0.05$), with higher blood glucose levels in the morning. There was a significant interaction between Test and Group ($F_{1, 28} = 39.30$, $p < 0.001$); simple effects analysis revealed that blood glucose levels did not differ between the two groups on the first test, but on the second test the glucose group's blood glucose level had significantly increased while the saccharine group's blood glucose readings remained unchanged ($p < 0.01$; see Figure 8a). There was also a significant interaction between Group and Time of day ($F_{1, 28} = 5.33$, $p < 0.05$); simple effects analysis revealed that this was due to a greater increase in blood glucose levels for the glucose group tested in the morning ($p < 0.05$; see Figure 8b). There was no interaction between Test and Time of day ($F < 1$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). Thus blood glucose levels were significantly raised following a glucose drink but not a saccharine drink, with a more pronounced increase for participants tested in the morning. These participants had higher blood glucose levels overall compared with those tested in the afternoon.

Table 8a: Means and standard deviation (in parentheses) for blood glucose levels (mmol/l) before and after a glucose or saccharine drink, stratified by time of day.

	Glucose (*n* = 16)		Saccharine (*n* = 16)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning **(*n* = 16)**	5.76 (0.82)	7.98 (0.70)	5.65 (0.94)	5.39 (1.02)
Afternoon **(*n* = 16)**	4.49 (1.05)	6.83 (1.17)	5.44 (0.75)	5.65 (0.77)
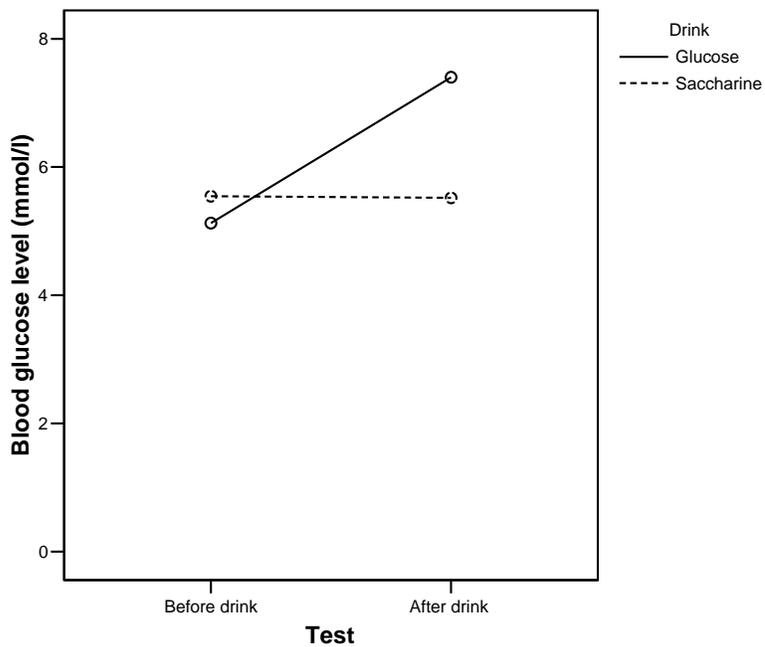
Figure 8a: Interaction between test time (before vs. after drink) and type of drink (glucose vs. saccharine) on mean blood glucose levels (collapsed across time of day).
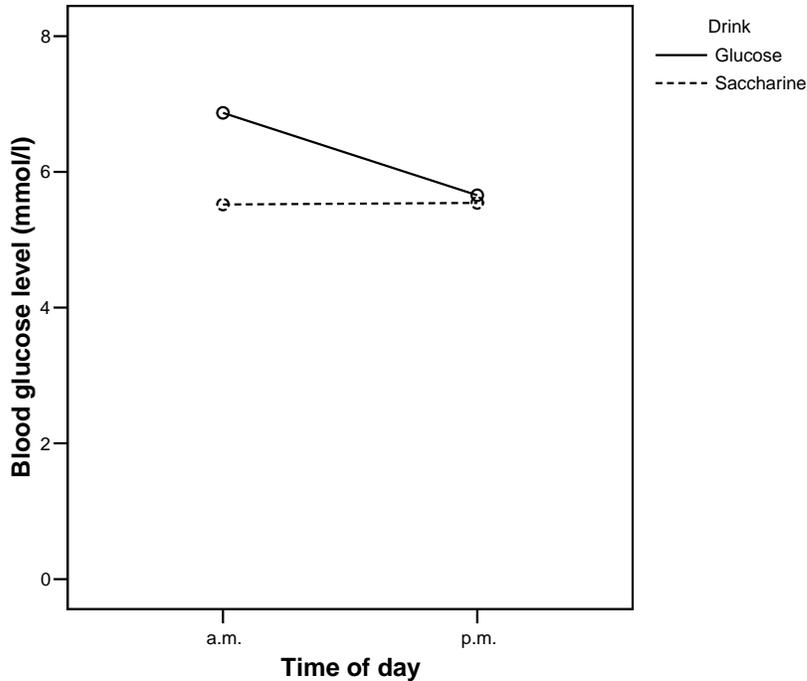
Figure 8b: Interaction between time of day (a.m. vs. p.m.) and type of drink (glucose vs. saccharine) on mean blood glucose levels (collapsed across test time).

For Energetic Arousal (EA) there was a significant main effect of Test ($F_{1, 28} = 27.61$, $p < 0.001$), with higher EA after the task. There were no effects of either Group ($F_{1, 28} = 3.01$, $p > 0.05$) or Time of day ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and Time of day ($F < 1$) or Group and Time of day ($F_{1, 28} = 2.03$, $p > 0.05$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). EA was generally higher on the second test, but this occurred irrespective of the drink consumed or the time of day. All means and standard deviations are shown in Table 8b.

Table 8b: Means and standard deviation (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day.

	Glucose (n = 16)		Saccharine (n = 16)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning (n = 16)	21.88 (2.36)	25.38 (2.20)	22.13 (4.02)	24.00 (3.89)
Afternoon (n = 16)	24.00 (2.98)	26.88 (4.42)	21.00 (2.62)	23.50 (2.56)

For Tense Arousal (TA) there were no effects of Test ($F_{1, 28}$ = 2.19, p > 0.05), Group ($F_{1, 28}$ = 1.39, p > 0.05) or Time of day (F < 1). There were no interactions between Test and Group (F < 1), Test and Time of day (F < 1) or Group and Time of day ($F_{1, 28}$ = 2.70, p > 0.05), nor was there a three-way interaction between Test, Group and Time of day ($F_{1, 28}$ = 3.42, p > 0.05). All means and standard deviations are shown in Table 8c.

Table 8c: Means and standard deviation (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day.

	Glucose (n = 16)		Saccharine (n = 16)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning (n = 16)	14.88 (3.91)	12.63 (2.50)	16.75 (3.99)	17.63 (4.84)
Afternoon (n = 16)	16.25 (4.46)	16.00 (3.85)	17.25 (6.23)	13.88 (2.48)

For Hedonic Tone (HT) there were no effects of Test ($F_{1, 28} = 3.02$, $p > 0.05$), Group ($F < 1$) or Time of day ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and Time of day ($F < 1$) or Group and Time of day ($F < 1$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). All means and standard deviations are shown in Table 8d.

Table 8d: Means and standard deviation (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day.

	Glucose ($n = 16$)		Saccharine ($n = 16$)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning ($n = 16$)	27.88 (3.83)	29.50 (2.00)	27.13 (4.58)	28.13 (3.72)
Afternoon ($n = 16$)	28.00 (3.21)	28.63 (3.74)	27.38 (2.88)	27.75 (3.50)

For State Anxiety there was a significant main effect of Test ($F_{1, 28} = 10.89$, $p < 0.01$), with lower State Anxiety after the task. There were no effects of either Group ($F < 1$) or Time of day ($F < 1$). There were no interactions between Test and Group ($F_{1, 28} = 1.92$, $p > 0.05$), Test and Time of day ($F < 1$) or Group and Time of day ($F < 1$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). State Anxiety was generally lower on the second test, but this occurred irrespective of the drink consumed or the time of day. All means and standard deviations are shown in Table 8e.

Table 8e: Means and standard deviation (in parentheses) for State Anxiety scores (min. = 20, max. = 80) before and after a glucose or saccharine drink, stratified by time of day.

	Glucose (*n* = 16)		Saccharine (*n* = 16)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning (*n* = 16)	33.25 (4.95)	29.50 (5.29)	38.63 (9.41)	32.50 (7.46)
Afternoon (*n* = 16)	34.50 (9.97)	33.50 (10.24)	38.75 (14.67)	33.25 (10.22)

The time taken in seconds to complete the Stroop task and the number of errors made were entered into two-way, between-subjects analyses of variance (ANOVA), with Group (glucose/saccharine) and Time of day (morning/afternoon) as the factors. All means and standard deviations are shown in Table 8f.

For the time taken to complete the task, there were no effects of either Group ($F < 1$) or Time of day ($F < 1$), nor was there an interaction ($F < 1$).

For the number of errors made there was a significant main effect of Group ($F_{1, 28} = 4.29$, $p < 0.05$), with fewer errors in the glucose group. There was no effect of Time of day ($F < 1$), nor was there an interaction ($F < 1$). Significantly fewer errors were made on the task following a glucose drink, but this occurred irrespective of time of day.

Table 8f: Means and standard deviation (in parentheses) for time taken and errors made in completing the Stroop task after a glucose or saccharine drink, stratified by time of day.

	Glucose (*n* = 16)		Saccharine (*n* = 16)	
	Morning **(*n* = 16)**	**Afternoon** **(*n* = 16)**	**Morning** **(*n* = 16)**	**Afternoon** **(*n* = 16)**
Time taken (secs)	175.75 (54.25)	184.25 (53.56)	184.50 (46.06)	194.13 (36.78)
Errors made **(min. = 0, max. = 185).**	4.63 (1.92)	4.75 (2.66)	7.75 (5.55)	8.13 (6.10)

To summarise, blood glucose levels were significantly raised following a glucose drink but not a saccharine drink, with a greater increase for participants tested in the morning. These participants also had higher blood glucose levels overall compared with those tested in the afternoon. Energetic Arousal was significantly higher and State Anxiety significantly lower following the Stroop task, but this occurred irrespective of the drink consumed or the time of day. Tense Arousal and Hedonic Tone were not affected by the task, the type of drink consumed or the time of day; nor was the time taken to complete the Stroop task. Errors made on the task were significantly lower among participants who had consumed a glucose drink, but this was again irrespective of the time of day.

4.3.4.3.2 Analysis 2: Type of drink, time of day and trait anxiety

The analyses in Analysis 1 were repeated to partial out the effects of Trait Anxiety on the mood and task performance variables examined. UMACL and STAI scores were entered into three-way, mixed design analyses of covariance (ANCOVA), with Test (before task vs. after task) as the within-subjects factor, Group (glucose/saccharine) and Time of day

(morning/afternoon) as the between-subjects factors and Trait Anxiety as the covariate. For full SPSS output, see Appendix D8.2

For Energetic Arousal (EA) there was no effect of the covariate Trait Anxiety ($F_{1, 27}$ = 2.96, $p > 0.05$). There were no effects of Test ($F_{1, 27}$ = 1.49, $p > 0.05$), Group ($F_{1, 27}$ = 1.92, $p > 0.05$) or Time of day ($F < 1$). There were no interactions between Test and Trait Anxiety ($F < 1$), Test and Group ($F < 1$), Test and Time of day ($F < 1$) or Group and Time of day ($F_{1, 27}$ = 1.40, $p > 0.05$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). All means with standard error are shown in Table 8g.

Table 8g: Means and standard error (in parentheses) for Energetic Arousal scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day. Values have been adjusted to partial out the effects of Trait Anxiety.

	Glucose (n = 16)		Saccharine (n = 16)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning (***n* = 16**)	21.65 (1.06)	25.15 (1.19)	22.00 (1.06)	24.38 (1.18)
Afternoon (***n* = 16**)	23.85 (1.06)	26.73 (1.18)	21.49 (1.10)	23.99 (1.23)

For Tense Arousal (TA) there was a significant effect of the covariate Trait Anxiety ($F_{1, 27}$ = 19.49, $p < 0.001$). Pearson's correlation revealed a significant positive correlation between TA and Trait Anxiety both before (r_{32} = 0.58, $p = 0.001$) and after the task (r_{32} = 0.36, $p < 0.05$). There were no effects of Test ($F < 1$), Group ($F < 1$) or Time of day ($F < 1$). There were no interactions between Test and Trait Anxiety ($F_{1, 27}$ = 1.20, $p > 0.05$) Test and Group ($F < 1$) or Test and Time of day ($F < 1$), nor was there a three-way interaction between Test, Group and Time of day ($F_{1, 27}$ = 2.75, $p > 0.05$). There was,

however, a significant interaction between Group and Time of day ($F_{1, 27} = 7.79$, $p = 0.01$). Simple effects analysis revealed that this was due to lower TA following a glucose drink, but only among participants tested in the morning ($p < 0.05$; see Figure 9). All means with standard error are shown in Table 8h.

Table 8h: Means and standard error (in parentheses) for Tense Arousal scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day. Values have been adjusted to partial out the effects of Trait Anxiety.

	Glucose ($n = 16$)		Saccharine ($n = 16$)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning (*n* = 16)	15.55 (1.41)	13.05 (1.13)	17.13 (1.40)	17.87 (1.12)
Afternoon (*n* = 16)	16.69 (1.40)	16.28 (1.12)	15.76 (1.46)	12.93 (1.17)
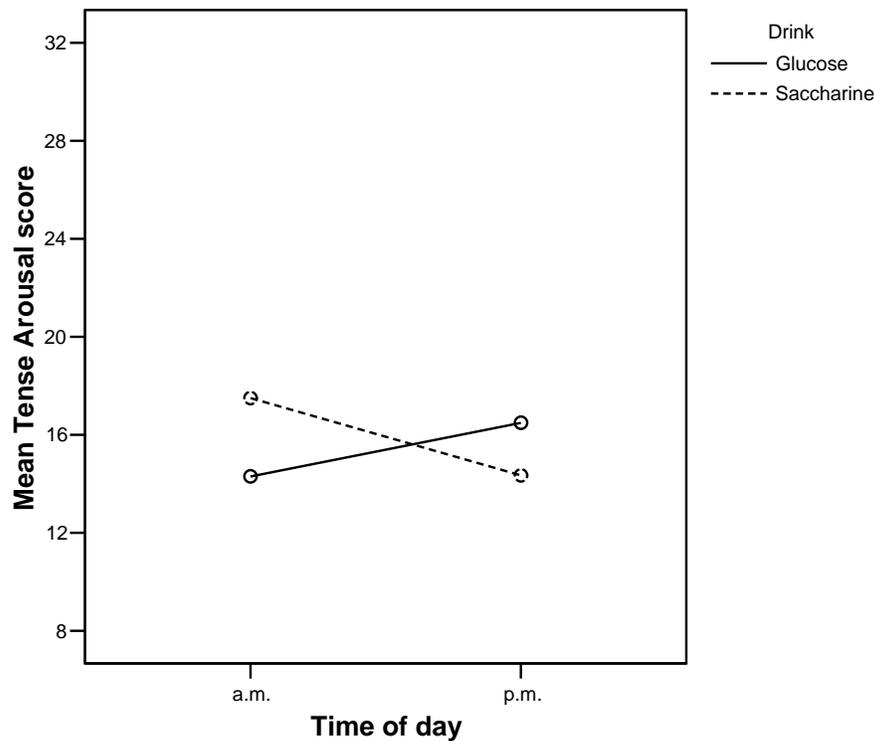
Figure 9: Interaction between time of day (a.m. vs. p.m.) and type of drink (glucose vs. saccharine) on mean Tense Arousal scores (collapsed across test time). Values have been adjusted to partial out the effects of Trait Anxiety.

For Hedonic Tone (HT) there was a significant effect of the covariate Trait Anxiety ($F_{1, 27}$ = 19.93, $p < 0.001$). Pearson's correlation revealed a significant negative correlation between HT and Trait Anxiety both before (r_{32} = -0.52, $p < 0.01$) and after the task (r_{32} = -0.66, $p < 0.001$). There were no effects of Test ($F < 1$), Group ($F < 1$) or Time of day ($F < 1$). There were no interactions between Test and Trait Anxiety ($F < 1$), Test and Group ($F < 1$), Test and Time of day ($F < 1$) or Group and Time of day ($F < 1$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). All means with standard error are shown in Table 8i.

Table 8i: Means and standard error (in parentheses) for Hedonic Tone scores (min. = 8, max. = 32) before and after a glucose or saccharine drink, stratified by time of day. Values have been adjusted to partial out the effects of Trait Anxiety.

	Glucose ($n = 16$)		Saccharine ($n = 16$)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning ($n = 16$)	27.39 (1.13)	28.97 (0.91)	26.85 (1.12)	27.83 (0.91)
Afternoon ($n = 16$)	27.68 (1.12)	28.27 (0.91)	28.45 (1.17)	28.94 (0.94)

For State Anxiety there was a significant effect of the covariate Trait Anxiety ($F_{1,27} = 62.22$, $p < 0.001$). Pearson's correlation revealed a significant positive correlation between State and Trait Anxiety both before ($r_{32} = 0.74$, $p = 0.001$) and after the task ($r_{32} = 0.79$, $p = 0.001$). There were no effects of Test ($F < 1$), Group ($F < 1$) or Time of day ($F < 1$). There were no interactions between Test and Trait Anxiety ($F < 1$), Test and Group ($F_{1, 27} = 1.49$, $p > 0.05$), Test and Time of day ($F < 1$) or Group and Time of day ($F_{1, 27} = 3.50$, $p > 0.05$), nor was there a three-way interaction between Test, Group and Time of day ($F < 1$). All means with standard error are shown in Table 8j.

Table 8j: Means and standard error (in parentheses) for State Anxiety scores (min. = 20, max. = 80) before and after a glucose or saccharine drink, stratified by time of day. Values have been adjusted to partial out the effects of Trait Anxiety.

	Glucose ($n = 16$)		Saccharine ($n = 16$)	
	Before drink	**After drink**	**Before drink**	**After drink**
Morning ($n = 16$)	35.16 (2.49)	31.23 (1.79)	39.69 (2.48)	33.47 (1.78)
Afternoon ($n = 16$)	35.76 (2.48)	34.64 (1.78)	34.52 (2.58)	29.42 (1.85)

The time taken in seconds to complete the Stroop task and the number of errors made were entered into two-way, between-subjects analyses of covariance (ANCOVA), Group (glucose/saccharine) and Time of day (morning/afternoon) as the factors and Trait Anxiety as the covariate. All means with standard error are shown in Table 8k.

For the time taken to complete the task there was no effect of the covariate Trait Anxiety ($F < 1$). There was no effect of Group ($F < 1$), no effect of Time of day ($F < 1$), and no interaction ($F < 1$).

For the number of errors made there was no effect of the covariate Trait Anxiety ($F_{1, 27} = 2.05$, $p > 0.05$). There was no effect of Group ($F_{1, 27} = 3.08$, $p > 0.05$), no effect of Time of day ($F < 1$), and no interaction ($F < 1$).

Table 8k: Means and standard error (in parentheses) for time taken and errors made in completing the Stroop task after a glucose or saccharine drink, stratified by time of day. Values have been adjusted to partial out the effects of Trait Anxiety.

	Glucose (*n* = 16)		Saccharine (*n* = 16)	
	Morning (*n* = 16)	**Afternoon (*n* = 16)**	**Morning (*n* = 16)**	**Afternoon (*n* = 16)**
Time taken (secs)	175.54 (17.50)	184.11 (17.41)	184.38 (17.39)	194.60 (18.07)
Errors made (min. = 0, max. = 185).	4.92 (1.55)	4.94 (1.55)	7.91 (1.55)	7.48 (1.61)

To summarise, higher Trait Anxiety was associated with greater Tense Arousal and State Anxiety and lower Hedonic Tone both before and after performing the Stroop task. Once the effects of Trait Anxiety had been partialled out, there were no effects of either the task, the type of drink consumed or the time of day on Energetic Arousal, Hedonic Tone, State Anxiety, the time taken to complete the Stroop task or the number of errors made. Tense Arousal was significantly lower following a glucose drink for participants tested in the morning. These effects occurred irrespective of testing time in relation to the task.

Due to the relatively small sample size for this study, power analyses were conducted for all nonsignificant effects with *F*-ratios of greater than 1 (see Appendix D8.3). Observed power values for these effects were low to moderate, ranging from 20-50%; thus the probability of Type II errors was increased.

Summarising all the results of Study 8, blood glucose levels tended to be higher in the morning compared with the afternoon. Blood glucose levels were significantly raised following a glucose drink but not a saccharine drink, with a more pronounced increase for participants tested in the morning. Energetic Arousal was significantly higher and State Anxiety lower following the task, irrespective of the drink consumed or the time of

day; however, when the effects of Trait Anxiety were partialled out these effects were no longer present. Conversely, Tense Arousal initially showed no effects of the task, the type of drink consumed or the time of day, but partialling out the effects of Trait Anxiety revealed that Tense Arousal was lower following a glucose drink for participants tested in the morning. The initial analysis also indicated fewer errors on the Stroop task following a glucose drink, although this effect also disappeared on partialling out Trait Anxiety. Hedonic Tone and the time taken to complete the Stroop task did not vary from pre- to post task, with the drink consumed or the time of day, with or without Trait Anxiety as a covariate. Higher Trait Anxiety corresponded to higher Tense Arousal and State Anxiety and lower Hedonic Tone both pre- and post-task. Overall, mood and anxiety responses to the Stroop task appear to be moderated by Trait Anxiety. Whilst a number of robust effects were demonstrated, power was fairly low for nonsignificant effects with F-ratios of greater than 1, indicating an increased risk of Type II errors for these effects.

4.3.4.4 Discussion

Blood glucose levels were generally higher in participants tested in the morning, which fits the diurnal trend reported in the literature (e.g. Troisi, Cowie & Harris, 2000). The morning group also displayed a greater increase in blood glucose following the glucose drink compared with the afternoon group.

Glucose also had a facilitating effect on task performance, with fewer errors made on the Stroop task when glucose was imbibed; however, this occurred irrespective of the time of day despite diurnal differences in both baseline and post-drink blood glucose levels. This may be due to the diurnal enhancement of blood glucose being too small to

exert an effect on cognition; alternatively, it may reflect compensation among those disadvantaged by lower blood glucose (see section 4.3.3.4). Existing evidence for beneficial effects of glucose for cognitive performance (see section 1.2.3 and Studies 6 and 7 – sections 4.3.2 and 4.3.3) is supported.

The initial analysis revealed no effects of glucose on mood, either in general or in response to the task. This contradicts the findings of Studies 6 and 7, as well as the literature on glucose, mood and cognition (section 1.2.3 and Studies 6 and 7). This may be partly due to the context in which the study took place. In the two previous studies participants were tested in a class setting, which had high ecological validity; in the present study participants were tested individually, which meant that the situation was quite artificial and clearly had no implications for them educationally.

Nevertheless, the moderating effects of trait anxiety were the most interesting findings of note. These effects were present in both performance on the task and in participants' responses to it. Partialling out the effects of trait anxiety removed the positive effect of glucose on the number of errors made, suggesting that the way in which an individual utilises glucose in cognitive functioning is somehow moderated by their level of trait anxiety. Partialling out trait anxiety also revealed an interaction between the type of drink consumed and the time of day on Tense Arousal scores, with reduced tension among the glucose group tested in the morning. This fits the pattern of higher blood glucose in the morning and increased absorption in this group, providing a direct association between blood glucose levels and tension. Again, it is suggested that the way in which an individual responds to a cognitively demanding task is somehow dependent on how anxious they are in general.

Overall the results of Study 8 highlight the role of anxiety in how individuals respond to demanding tasks, although the small sample size means that there may have been additional effects that went undetected. Like the previous studies there are implications for workplace stress; it is suggested that some individuals may be more prone to the effects of stressors than others. The efficacy of measures taken to reduce these effects is likely to be dependent, at least partly, on how stressors are dealt with in the first place.

4.3.5 Summary of blood glucose and cognitive task response studies

The prevailing finding in this subset of studies is that raising blood glucose levels can have beneficial effects for both mood and performance, and may even improve the way in which an individual responds to a situation requiring cognitive effort. It is clear that low blood glucose should be avoided if a positive mood state and optimum cognitive performance are to be maintained; this is applicable to both workplace and educational contexts.

These results should nonetheless be interpreted with caution and must take into account the implications for general health. Although these studies all demonstrated some positive effects of glucose ingestion, they achieved this by effectively 'spiking' blood glucose levels. Glucose and other high-sugar foods and drinks have a very high glycaemic index (G.I.); ingestion of high G.I. substances causes a rapid increase (spiking) in blood glucose levels, which is followed by a rebound effect whereby large amounts of insulin are released to bring levels back to the set point of 5 mmol/l (for a more detailed explanation of this process see section 1.2.2). This rebound has detrimental effects on

mood and cognition (see Thayer, 1989); moreover, continued spiking and rebounding may lead to Type II diabetes, which has dangerous health consequences as well as being associated with cognitive or educational deficits (see section 1.2.3).

Furthermore, very high blood glucose levels, or hyperglycaemia (>7 mmol/l; see Lock *et al.*, 2001) are just as damaging to cognitive processes as a hypoglycaemic state. Whilst moderate increases in blood glucose have positive effects, as demonstrated in this study subset, much larger increases tend to produce drowsiness (Benton, 1996). It appears that glucose ingestion works most effectively not by raising blood glucose levels *per se*, but rather by ameliorating or preventing the negative effects of hypoglycaemia. Thus the ideal situation would be to maintain a stable blood glucose level, which is best achieved by eating regular, balanced meals with a lower G.I.

To summarise, the results from the blood glucose studies considered alongside those from the circadian rhythm studies (see section 4.1) indicate that mood and stress are regulated by a complex interaction of factors, including blood glucose levels, time of day, situational variables and individual differences. The importance of nutrition and the maintenance of stable blood glucose levels is emphasised.

4.4 Blood glucose and biological rhythm studies

4.4.1 Introduction to blood glucose and biological rhythm studies

Previous studies have suggested that blood glucose levels and their effects on mood are influenced by biological rhythms. This subset of studies explores changes in blood glucose levels throughout the course of the working day and how they relate to changes in mood. The first study simply compares hourly recordings of blood glucose and mood; the second brings in the menstrual cycle, which has been linked to both mood and changes in glycaemic control, to examine this relationship at a time where mood is likely to be less positive, i.e. around menstruation. These studies build upon the previous suggestions of a menstrual-circadian interaction on mood to provide some explanation of the physiology underlying this interaction.

4.4.2 Study 9: 12-hour blood glucose levels and mood.

4.4.2.1 Introduction

As discussed and demonstrated in the previous section (4.3), the influence of blood glucose levels on mood is well documented. Furthermore, there is consistency between diurnal rhythms of blood glucose levels (Troisi, Cowie & Harris, 2000) and mood (Thayer, 1989), suggesting an underlying circadian component to this relationship. Whilst the previous study series examined the immediate impact of altered blood glucose levels on mood, fluctuations in blood glucose during a normal day are likely to be more subtle, with diurnal rhythms playing a role as well as routines relating to and affecting food intake. Thus, this study examines this relationship in more detail, comparing blood glucose levels and mood over the course of the working day.

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A detailed review of circadian rhythm effects on blood glucose levels and mood can be found in sections 1.2.4 and 1.4.2. Moderately, but not excessively high blood glucose levels are associated with a more positive mood state, namely a state of calm-energy. Furthermore, both blood glucose and positive mood tend to be greater in the morning.

Research on blood glucose rhythms is complicated somewhat by the fact that blood glucose levels are directly influenced by the intake of calories throughout the day. Similarly, mood is highly susceptible to external events (see section 1.2.1). It might therefore be argued that the only way to obtain a true measure of diurnal blood glucose variations and their effects on mood would be to take these measures while fasting, and within a constant environment. Considered from an applied viewpoint, however, the usefulness and indeed validity of this approach is questionable. In reality most individuals will take in food and drink, albeit often sporadically, over the course of a typical day. Failing to do so is in itself likely to affect mood; in other words, taking part in such an experimental procedure would probably produce confounding effects that would outweigh the benefits of obtaining a 'pure' measure of diurnal blood glucose and mood rhythms.

For this reason, the present study was conducted in a way that enabled participants to incorporate self-testing into their regular daily routines, recording their blood glucose levels and mood every hour for 12 consecutive hours starting at 9.a.m. Based on the established diurnal rhythms of both blood glucose levels and mood and the well-known relationship between these two variables, it was expected that:

1) Higher blood glucose would be associated with a more positive mood state, demonstrated by increased Energetic Arousal and Hedonic Tone and decreased Tense Arousal;

2) There would be a significant effect of the time of day on both blood glucose levels and mood;

3) Blood glucose levels would be higher and mood more positive in the morning compared with the afternoon.

4.4.2.2 Method

4.4.2.2.1 Participants

10 participants (3 male, 7 female) aged 18 to 34, with a mean age of 22.40 years (s.d. = 4.93) completed the study. Diabetics, pregnant women and any individuals with serious medical conditions were excluded.

4.4.2.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). Booklets were made up containing an information sheet (see Appendix B9.1), an informed consent form (see Appendix B9.2), and 12 copies of the UMACL. The first UMACL contained spaces for the participant to indicate their sex and age; all UMACLs included spaces for the participant to note the time of testing, their blood glucose reading and any food or drink consumed in the last hour.

Blood glucose level was tested using BM-Test 1-44 blood glucose test strips, following the manufacturer's procedure, then measured with a Prestige Medical Healthcare Ltd. HC1 digital Blood Glucometer. Participants were provided with sterile wipes for cleaning fingers before testing and sticking plasters to cover the wounds; they were also equipped with portable sharps containers for disposal of any blood-contaminated materials. A mobile telephone was used to contact participants via text messaging.

4.4.2.2.3 Procedure

Participants attended an initial briefing session individually, in which a full demonstration was given for the self-testing blood glucose levels. The full procedure was also detailed in the information sheet. The session was also used to eliminate any potential volunteers with relevant medical conditions, including allergies to sticking plasters. Participants were given the questionnaire booklets and blood testing materials to take away with them so that they could complete the study during the course of their normal day; the day of testing was agreed during the briefing and a follow-up appointment made for the debriefing and return of materials.

Informed consent forms were completed during the briefing; once completed these were detached from the booklets and returned immediately before proceeding with the study. The Consent forms were the only sheets containing participants' names; to ensure anonymity these were filed separately from the raw data. Each participant also provided their mobile telephone number, which was entered into the telephone used for

the study under their unique participant number. Again, names were not used. Telephone numbers were deleted upon completion of the study.

On the agreed day of testing, the participant was contacted via text message ('Please complete UMACL and test blood glucose') every hour on the hour from 9 a.m. to 8 p.m. Participants were requested to complete the testing within 15 minutes of being contacted; if half an hour had elapsed they were advised to skip that test and leave the questionnaire for that hour blank. No participants did this, and none failed to provide a blood glucose reading for any of the testing times.

The participant then attended their follow-up appointment (usually within one week of completing the study) to return their materials, in which they were fully debriefed on the purpose of the study. Sharps containers were disposed of for incineration.

4.4.2.3 Results

Raw data can be found in Appendix C9, with full SPSS analysis in Appendix D9.

4.4.2.3.1 Analysis 1: Correlations and partial correlations between blood glucose and mood

For raw data see Appendix C9.1; for full SPSS output, see Appendix D9.1. A series of bivariate Pearson's correlations (one-tailed) was used to correlate blood glucose level with scores on each UMACL subscale for each hour (total number of observations = 120). Energetic Arousal (EA) was positively, albeit weakly correlated with blood glucose

level ($r_{120} = 0.15$, $p < 0.05$), as was Hedonic Tone (HT: $r_{120} = 0.18$, $p < 0.025$). Blood glucose level was not correlated with Tense Arousal (TA: $r_{120} = 0.04$, $p > 0.05$).

The analysis was then repeated in a series of partial correlations to control for the time of day. Energetic Arousal (EA) was still positively, albeit weakly correlated with blood glucose level ($r_{117} = 0.15$, $p = 0.05$), as was Hedonic Tone (HT: $r_{120} = 0.17$, $p < 0.05$). Blood glucose level was again not correlated with Tense Arousal (TA: $r_{117} = 0.03$, $p > 0.05$).

To summarise, a higher blood glucose level was associated with increased Energetic Arousal and Hedonic Tone. No relationship was found between blood glucose levels and Tense Arousal.

4.4.2.3.2 Analysis 2: Comparing blood glucose levels and mood in the morning, afternoon and evening

For raw data see Appendix C9.2; for full SPSS output, see Appendix D9.2. Blood glucose levels and ratings on each UMACL subscale were entered into one-way, within-subjects analyses of variance to compare the morning (9 a.m.), afternoon (1 p.m.), evening (5 p.m.) and later evening (8 p.m.). All means and standard deviations can be found in Table 9.

Blood glucose level did not differ across the time of day ($F < 1$). With regards to mood, Energetic Arousal (EA) varied significantly across the day ($F_{3, 27} = 3.57$, $p < 0.05$); *post hoc* pairwise comparisons indicated that EA was lower in the morning (9 a.m.) than at any other time ($p < 0.05$). There was no effect of time on Tense Arousal (TA: $F < 1$) or Hedonic Tone (HT: $F_{3, 27} = 1.46$, $p > 0.05$).

Table 9: Blood glucose levels and UMACL scores across the day ($N = 10$).

	Morning (9 a.m.)	Afternoon (1 p.m.)	Evening (5 p.m.)	Late evening (8 p.m.)
Blood glucose (mmol/l)	4.87 (1.24)	5.45 (1.06)	5.49 (1.38)	5.49 (0.98)
Energetic Arousal (min. = 8, max. = 32)	17.50 (3.63)	21.00 (3.06)	21.00 (1.76)	20.50 (3.72)
Tense Arousal (min. = 8, max. = 32)	17.00 (4.76)	16.00 (3.68)	15.70 (4.22)	17.00 (2.49)
Hedonic Tone (min. = 8, max. = 32)	23.40 (4.97)	25.70 (2.71)	26.00 (3.16)	25.50 (2.17)

To summarise all the results of Study 9, increased blood glucose level was associated with greater Energetic Arousal and Hedonic Tone, but was unrelated to Tense Arousal. These effects remained even after controlling for the time of day. Energetic Arousal was lower in the morning compared with the afternoon and early to late evening, but neither blood glucose levels nor any of the other mood dimensions showed significant diurnal variations.

4.4.2.4 Discussion

The results of this study are consistent with well-established findings of more positive mood with higher blood glucose levels. Regardless of the time of day, a higher blood glucose level was associated with increased Energetic Arousal (EA) and Hedonic Tone (HT). Findings from the previous studies (see section 4.3), which directly manipulated blood glucose levels, are supported.

Unlike those studies, however, this one revealed no association between blood glucose level and Tense Arousal (TA). One explanation for this may be that in those studies, glucose drinks were used to raise blood glucose levels substantially. In the

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present study, participants' blood glucose levels were solely dependent on what they consumed throughout the day; given that most foods will not raise blood glucose as rapidly as pure glucose (which has a G.I. of 100) but will release energy more slowly over a period of time, this would have resulted in a more subtle effect on blood glucose (see section 1.2.2). Alternatively, participants in the previous studies were taking part in an experimental situation and this may have increased sensitivity to mood change.

The fact that the dimensions of the UMACL associated with more 'positive' mood (i.e. EA and HT) were affected and not the more 'negative' dimension (i.e. TA) is interesting. It indicates, as with the findings regarding the menstrual cycle (see section 4.2), that mood variations as a function of the time of day are sometimes less positive, but not necessarily more negative. As participants were in control of their own blood glucose levels during the study, this suggests that throughout a 'typical' day individuals will automatically regulate their own blood glucose to avoid the lower levels associated with more negative mood. Moreover, experiments that artificially induce a hypoglycaemic state (see section 1.2.3) produce results seldom found in the 'real' world, even when the actual blood glucose levels are similar.

With regards to circadian rhythms, blood glucose levels showed no diurnal changes, which contradicts evidence of higher levels in the morning (Troisi, Cowie & Harris, 2000; see Study 8, section 4.3.4). Again this is possibly due to participants self-regulating their blood glucose levels over the course of the day; individuals may well respond automatically to any diurnal changes in blood glucose, so that these would be masked in a naturalistic study of this kind. In addition, given that the sample consisted of

young, healthy individuals, blood glucose levels would have been stabilised fairly rapidly with the intake or absence of food (see section 1.2.2).

Mood, on the other hand, showed some diurnal variation in the form of lower Energetic Arousal in the morning compared with the afternoon and evening. Whilst this contradicts the 'typical' pattern of less positive mood in the afternoon (Thayer, 1989), it does concur with some previous study findings (see Study 1, 4.1.2 and Study 8, 4.3.4). One possibility, as explained previously, is that this pattern may reflect adaptation to a less 'morning-focused' routine among this particular sample. If, as Thayer proposes, mood is less positive upon waking and does not peak until later in the morning, then someone who rises later in the morning will not experience this peak until later in the day.

As for the diurnal change in mood despite the apparent lack of a diurnal blood glucose rhythm, this may be explained by the mechanisms by which blood glucose levels are held constant (see section 1.2.2). The affective costs of mobilising glycogen from the liver and muscles, compared to having glucose readily available in the bloodstream, may have caused a reduction in Energetic Arousal even though blood glucose levels remained stable.

In conclusion, this study illustrates the relationship between blood glucose levels and mood, with some evidence of a circadian influence. More importantly, the findings suggest that individuals are able to 'self-medicate' on a routine basis to regulate their own blood glucose levels and mood. This has useful implications for maintaining a positive mood state throughout the course of the working day.

4.4.3 Study 10: Menstrual cycle effects on 12-hour blood glucose levels and mood.

4.4.3.1 Introduction

Previous studies have suggested that the time of the day interacts with the menstrual cycle to influence mood. This study follows on directly from Study 9 to determine whether the fluctuations in mood noted across the day are the same for women in the premenstrual to menstrual phases of their cycles, where mood is likely to be less positive (see section 4.2).

The role of blood glucose levels in enhancing or maintaining a positive mood state have been demonstrated in the previous study series (section 4.3) and in Study 9. The mood dimension most consistently affected is Energetic Arousal, which was also the case in the menstrual cycle study series (section 4.2). Given that levels of subjective energy are closely linked with blood glucose levels, alongside evidence of menstrual cycle-related changes in glycaemic control (see section 1.2.5), it is possible that blood glucose may also play a part in the mood states associated with the menstrual cycle.

As discussed previously, self-medication is an important factor in mood fluctuations throughout the day, and will thus influence how women respond to cyclic changes in mood. Evidence for premenstrual changes in appetite (Cawood, Bancroft & Steel, 1993) may indicate that women unconsciously regulate their blood glucose levels in response to cyclical changes. The aim of the present study was therefore to gain some insight into the physiology underlying perimenstrual mood states, with a view to applying the findings to suggest interventions for maintaining psychological well-being during this time.

As with study 9, the present study was conducted in a way that enabled participants to incorporate self-testing into their regular daily routines, recording their blood glucose levels and mood every hour for 12 consecutive hours starting at 9.a.m. The only difference was that they were asked to test themselves specifically during the week prior to or during menstruation. Based on the findings of Study 9 and previous study series (4.2 and 4.3), it was anticipated that:

1) Higher blood glucose would be associated with a more positive mood state, i.e. increased Energetic Arousal (EA) and Hedonic Tone (HT) and reduced Tense Arousal (TA);

2) There would be a significant effect of the time of day on both blood glucose levels and mood;

3) Mood would be less positive (i.e. lower EA and HT and higher TA) among this sample of participants compared with those in Study 9.

Taking into account the menstrual-circadian interaction reported in section 4.2.4, it was considered possible that any diurnal changes in mood observed here would differ from those found in Study 9.

4.4.3.2 Method

4.4.3.2.1 Participants

11 female participants aged 19 to 34, with a mean age of 21.09 years (s.d. = 4.32) completed the study. 7 had natural menstrual cycles and 4 were oral contraceptive users. Diabetics, pregnant women and any individuals with serious medical conditions were excluded.

4.4.3.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL). Booklets were made up containing an information sheet (see Appendix B10.1), an informed consent form (Appendix B10.2), a menstrual questionnaire (Appendix B10.3) containing questions on age, parity, contraception and date of last menstrual period (LMP), and 12 copies of the UMACL. The information sheet required the participant to tick a box indicating whether they were completing the study in the week prior to or the week during menstruation. The first UMACL contained spaces for the participant to indicate their sex and age; all UMACLs included spaces for the participant to note the time of testing, their blood glucose reading and any food or drink consumed in the last hour.

Blood glucose level was tested using BM-Test 1-44 blood glucose test strips, following the manufacturer's procedure, then measured with a Prestige Medical Healthcare Ltd. HC1 digital Blood Glucometer. Participants were provided with sterile wipes for cleaning fingers before testing and sticking plasters to cover the wounds; they were also equipped with portable sharps containers for disposal of any blood-contaminated materials.

4.4.3.2.3 Procedure

Participants attended an initial briefing session individually, in which a full demonstration was given for the self-testing blood glucose levels. The full procedure was also detailed in the information sheet. The session was also used to eliminate any potential volunteers with relevant medical conditions, including allergies to sticking plasters. Participants were given the questionnaire booklets and blood testing materials to

take away with them so that they could complete the study during the course of their normal day; half were asked to select a day during their premenstrual week, and the other half to select a day during menstruation. A follow-up appointment was made for 5 weeks later for the debriefing and return of materials; this gave sufficient time for participants to have reached the right stage of their menstrual cycle.

Informed consent forms were completed during the briefing; once completed these were detached from the booklets and returned immediately before proceeding with the study. The Consent forms were the only sheets containing participants' names; to ensure anonymity these were filed separately from the raw data.

On the chosen day of testing, participants were requested to complete the testing within 15 minutes of each hour; it was recommended that they set an hourly alarm on their mobile telephones as a reminder. If half an hour had elapsed they were advised to skip that test and leave the questionnaire for that hour blank. No participants did this, and none failed to provide a blood glucose reading for any of the testing times.

The participant then attended their follow-up appointment 5 weeks later to return their materials, in which they were fully debriefed on the purpose of the study. Sharps containers were disposed of for incineration.

4.4.3.3 Results

Raw data can be found in Appendix C10, with full SPSS analysis in Appendix D10.

4.4.3.3.1 Analysis 1: Correlations and partial correlations between blood glucose and mood

For raw data see Appendix C10.1; for full SPSS output, see Appendix D10.1. A series of bivariate Pearson's correlations (one-tailed) was used to correlate blood glucose level with scores on each UMACL subscale for each hour (total number of observations = 132). Blood glucose level was not correlated with Energetic Arousal (EA: $r_{132} = 0.033$, $p > 0.05$), Tense Arousal (TA: $r_{132} = -0.006$, $p > 0.05$), or Hedonic Tone (HT: $r_{132} = 0.023$, $p > 0.05$).

The analysis was then repeated in a series of partial correlations to control for the time of day. Again, blood glucose level was not correlated with Energetic Arousal (EA: $r_{132} = -0.008$, $p > 0.05$), Tense Arousal (TA: $r_{132} = 0.004$, $p > 0.05$), or Hedonic Tone (HT: $r_{132} = -0.018$, $p > 0.05$).

To summarise, no relationship was found between blood glucose levels and any mood dimension, even when controlling for time of day.

4.4.3.3.2 Analysis 2: Comparing blood glucose levels and mood in the morning, afternoon and evening

For raw data see Appendix C10.2; for full SPSS output, see Appendix D10.2. Blood glucose levels and ratings on each UMACL subscale were entered into one-way, within-subjects analyses of variance to compare the morning (9 a.m.), afternoon (1 p.m.), evening (5 p.m.) and later evening (8 p.m.). All means and standard deviations can be found in Table 10.

Blood glucose level did not differ across the time of day ($F_{3, 30} = 1.37$, $p > 0.05$). With regards to mood, Energetic Arousal (EA) varied significantly across the day ($F_{3, 30} = 4.17$, $p = 0.01$); *post hoc* pairwise comparisons indicated that EA was lower in the morning (9 a.m.) than at any other time ($p < 0.05$). There was a significant effect of time on Tense Arousal (TA: $F_{3, 30} = 4.36$, $p = 0.01$), with TA lower in the evening (5 p.m.) than at all other times ($p < 0.05$). There was also a significant effect of time on Hedonic Tone (HT: $F_{3, 30} = 2.95$, $p < 0.05$), with lower HT in the morning compared with the evening ($p < 0.05$).

To summarise, Energetic Arousal and Hedonic Tone varied significantly across the day, being at their lowest in the morning and highest in the evening. This corresponded to significant diurnal variations in Tense Arousal, which was highest in the morning and lowest in the afternoon. There were no effects of time of day on blood glucose levels.

Table 10: Blood glucose levels and UMACL scores across the day among women in the perimenstruum.

	Morning (9 a.m.)	Afternoon (1 p.m.)	Evening (5 p.m.)	Late evening (8 p.m.)
Blood glucose (mmol/l)	4.78 (0.97)	5.17 (1.00)	5.46 (1.14)	5.67 (1.62)
Energetic Arousal (min. = 8, max. = 32)	16.36 (4.50)	20.91 (4.61)	22.27 (3.88)	21.18 (4.79)
Tense Arousal (min. = 8, max. = 32)	18.27 (4.29)	16.82 (2.75)	14.18 (3.40)	17.91 (3.18)
Hedonic Tone (min. = 8, max. = 32)	21.00 (4.75)	23.45 (5.17)	26.27 (3.10)	25.09 (3.91)

To summarise all the results of Study 10, blood glucose level was not associated with scores on any mood dimension among women in the premenstrual to menstrual weeks, even when controlling for the time of day. Blood glucose levels also showed no diurnal variations. However, Energetic Arousal and Hedonic Tone were lower in the morning and higher in the evening. This corresponded to significant diurnal variations in Tense Arousal, which was highest in the morning and lowest in the evening.

4.4.3.4 Discussion

Although the positive relationship between blood glucose level and Energetic Arousal found in the previous study (Study 9) was not replicated here, more prominent effects of time of day on mood were demonstrated. As with Study 9, Energetic Arousal was lowest in the morning; however, in this study an evening peak was also evident. Similar trends were also noted for Hedonic Tone, corresponding to a morning peak and evening dip in Tense Arousal. Overall, mood was more positive in the evening in the sense that it was closest to a calm-energetic state.

What these findings suggest is that diurnal effects on mood are exacerbated among women in the premenstrual to menstrual weeks. Rather than being less positive *per se*, mood appears to be more susceptible to changes during this time. The results show some support for the findings of the menstrual cycle study series (see section 4.2), which demonstrated that Energetic Arousal (Studies 3, 4 and 5: see sections 4.2.2, 4.2.3 and 4.2.4) and Hedonic Tone (Study 4: 4.2.2) were sensitive to menstrual cycle-related changes; Study 4 also indicated lower Hedonic Tone in the perimenstruum, which was

also true for the present study in comparison to the previous (Study 9; see Tables 9 and 10 for means, sections 4.4.2.3 and 4.4.3.3).

The notion of a menstrual-circadian interaction (see Study 5, section 4.2.4) is also supported; although Study 5 only found this to be the case among naturally cycling women, the majority of the present sample (7 of 11) also had natural menstrual cycles (i.e. were not using oral contraceptives). Though situational and contextual differences mean that it is difficult to draw direct comparisons between the different study series, the suggestion that diurnal mood variations are influenced by menstrual cycle phase is interesting and has potential implications for the management of everyday moods.

As with the previous study in this subset, blood glucose levels did not show any significant diurnal variation. Again, this suggests that among young, healthy individuals blood glucose levels will be held fairly constant throughout the day through both the physiological regulatory mechanisms (see section 1.2.2) and self-regulation by food intake. Blood glucose levels at the specified time points were also comparable between studies (see Tables 9 and 10), indicating that they were not altered perimenstrually. This does not support evidence for menstrual cycle-related changes in glycaemic control (see section 1.2.5); however, important methodological and sampling differences need to be taken into account. Much of this evidence comes from diabetic women (e.g. Lunt & Brown, 1996; Cawood, Bancroft & Steel, 1993) and none of the present study participants were diabetic. Other studies have found slightly lower levels of fasting blood glucose among nondiabetic oral contraceptive users (e.g. Troisi, Cowie & Harris, 2000b; Kjos *et al.*, 1993), but the majority of the present study participants had natural menstrual cycles. Moreover, these studies tended to be carried out on fasting subjects. Because the

aim of the present research was to examine changes in everyday moods during the course of an individual's typical day rather than the pure biology of these changes, it would not have been practical or useful to require participants to fast for the duration of these studies. Nevertheless, further research might consider diurnal changes among individuals who are already fasting, for example during Ramadan (see Reilly & Waterhouse, 2007), to obtain a measure of the physiological processes underlying mood fluctuations in a situation where fasting is the norm rather than an experimental requirement.

In conclusion, the results of this study indicate that diurnal fluctuations in mood are influenced and possibly even exacerbated during the premenstrual weeks. Whilst evidence for changes in blood glucose levels both diurnally and menstrually are not supported here, the findings concur with those of the previous study in this subset to suggest that individuals will self-regulate their own blood glucose levels during the course of a typical day.

4.4.4 Summary of blood glucose and biological rhythm studies

This subset of studies demonstrates further how mood is influenced by interactions between biological rhythms, showing that diurnal changes in mood are more evident among women in their premenstrual to menstrual phases. The first of these studies (Study 9) also provides some evidence for an association between blood glucose levels and mood, supporting the findings of the previous subset (section 4.3). Energetic Arousal was once more the most often affected mood dimension, correlating significantly with blood glucose level in Study 9 and being significantly lower in the morning both in general (Study 9) and among women in the perimenstruum (Study 10). In Study 10, however, an

evening peak in EA was also noted. Furthermore, similar trends were observed for Tense Arousal and Hedonic Tone, indicating a more tense-tired and less pleasant mood in the morning and a more calm-energetic and pleasant mood in the evening. This does not suggest that mood is generally less positive around and during menstruation; simply that sensitivity to changes in mood may be enhanced at this time.

Whilst blood glucose levels showed no significant diurnal variations in either study, it is important to consider the way in which these studies were carried out. The naturalistic methods employed meant that the absence of diurnal changes were possibly a reflection of good glycaemic control among young and healthy participants, as well as unconscious self-regulation of blood glucose levels by food intake throughout the day. The next and final study subset (section 4.5) investigates the 'self-medication' concept further, suggesting methods to set and then maintain a calm-energetic baseline throughout the working day.

4.5 Intervention studies

4.5.1 Introduction to intervention studies

This final subset of studies utilises the findings from the previous studies to suggest simple interventions for maintaining a positive mood state. Having established that mood is likely to be less positive around menstruation, interventions were tested for their efficacy during this time. The first study examined the effects of taking a daily aromatherapy bath to enhance mood state, with the aim to test whether the known beneficial properties of a daily bathing regimen could be extended to the premenstrual and menstrual phases of the cycle. The second study used chocolate to enhance positive mood, comparing women in their midcycle phase with those in the week prior to or during menstruation. These interventions are relatively simple measures that could easily be incorporated into an individual's everyday routine, and demonstrate the application of positive psychology in maintaining psychological well-being.

4.5.2 Study 11: Using aromatherapy baths to maintain a positive perimenstrual mood state.

4.5.2.1 Introduction

Within a positive psychological framework, 'preventative' measures may be taken to prevent stress and negative mood from reaching problematic levels (see section 1.1.3). Simple lifestyle changes may help to achieve this, setting a calmer baseline each day to provide an 'innoculation' against oncoming stressors (Martino & Morris, 2004). Taking the time for a daily bath is one such method. Whilst there may be a tendency to opt for showers to save time, it has been suggested (Morris, 2002) that a bath may be

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psychologically efficacious and that the addition of aromatherapy oils to the bath may augment the psychological benefits. Lavender oil is almost universally purported by aromatherapists to have both physical and psychological benefits (Saeki, 2000; Lawless, 1994).

Mood is subject to change as a result of many factors, not just obvious stressors. Fluctuations in mood relating to biological rhythms mean that there may be times when individuals are more prone to stressors. It therefore makes sense to implement interventions to maintain a calm baseline during times where mood is likely to be less positive. The menstrual cycle is one biological rhythm that has been at the centre of many mood studies in recent years (see section 1.3.4 for a detailed review). As demonstrated in previous studies (see section 4.2), mood state tends to be less positive in terms of subjective energy and somatic comfort around the time of menstruation. Indeed, there is possibly a causal relationship between physical symptoms and negative mood symptoms during menstruation (Cockerill, Wormington & Nevill, 1994).

This study was a follow-up to that of Morris (2002). The aim was to test whether the energising and calming effects of lavender baths found in the original bath study could also extend to the weeks prior to and during menstruation, where mood is likely to be less positive. Participants had their mood measured at the start and at the end of a two-week bathing regimen, during which they added either lavender oil mixed with a grapeseed base oil to their bath, or grapeseed oil only (a 'placebo' condition). Participants were not made aware that there were two conditions. The two-week bathing regimen for each participant was scheduled to begin a week before menstruation was due, so that the

premenstrual and menstrual weeks would be captured. Based on the previous studies it was anticipated that:

1) Mood would be more positive at the end of the two-week bathing regimen;

2) These effects would be exacerbated in participants who used the oil containing lavender.

4.5.2.2 Method

4.5.2.2.1 Participants

24 female students from the University of Wolverhampton aged 18 to 34 years (mean age = 20.33; s.d. = 3.41) participated in the study, with 12 in each of the two conditions. Individuals who knew they were pregnant, or had cardiovascular problems, asthma or skin allergies were excluded.

4.5.2.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). Booklets were made up consisting of an information sheet (see Appendix B11.1), an informed consent form (Appendix B11.2) and two copies of the UMACL. Also included in the booklet was a participant details questionnaire (Appendix B11.3) containing questions on age, parity, contraception, date of last menstrual period (LMP) and preference for baths or showers, and some diary sheets (Appendix 11.4) on which to note the date, whether a bath had been taken with the oil that day, whether the participant had started or was still menstruating that day and any unusually stressful events that had occurred.

Those in the lavender condition received a dropper bottle containing 80% grapeseed massage oil plus 20% (by volume) lavender essential oil. Those in the grapeseed condition (placebo) received a bottle containing grapeseed oil only.

4.5.2.2.3 Procedure

Volunteers for the study attended a brief, 10-minute meeting with the researcher to collect materials. At the meeting they were given appropriate materials and instructions on how to use them, along with contact details of the researcher in case they had any problems or queries. The consent form was completed and detached from the booklet; to ensure anonymity these were the only sheets requiring the participants' names, and were filed separately from the raw data. Finally, each individual was required to apply one drop of their oil onto their forearm for 30 minutes. If this produced any irritation they were told to return the materials and not proceed with the study.

Booklets were numbered consecutively; odd numbers were allocated grapeseed and even numbers were lavender, although participants were not made aware that there were two conditions. Instead they were simply told that they were being given 'bath oil'.

Participants were asked to begin the study one week before their next menstrual period was due. They would take a bath daily for at least 10 minutes each time, over a period 14 days, adding 3ml of oil to each bath. They chose their own time of bathing, but were requested to keep as close as possible to the same time each day. The first UMACL was to be completed before the first bath (Day 1) along with the participant details questionnaire, and the second after the final bath (Day 14). Data were deemed usable if at least 10 baths were taken during the 14 days, with each bath occurring within

approximately one hour of the first. The diary sheets were used to confirm menstrual cycle phase.

4.5.2.3 Results

Raw data can be found in Appendix C11, with full SPSS analysis in Appendix D11. Scores on each dimension of the UMACL were entered into two-way, mixed design analyses of variance (ANOVA), with Test (start vs. end of the bathing regimen) as the within-subjects factor and Group (lavender or grapeseed) as the between-subjects factor. All means and standard deviations can be found in Table 11.

For Energetic Arousal (EA) there was a significant main effect of test, with higher EA at the end of the bathing regimen ($F_{1, 22} = 11.99$, $p < 0.01$). The main effect of Group only just reached significance ($F_{1, 22} = 4.29$, $p = 0.05$); EA was generally higher in the lavender group. There was no interaction ($F_{1, 22} = 1.85$, $p > 0.05$).

For Tense Arousal (TA) there was no effect of test ($F_{1, 22} = 2.35$, $p > 0.05$), no effect of Group ($F_{1, 22} = 2.05$, $p > 0.05$) and no interaction ($F < 1$).

For Hedonic Tone (HT) there was a significant main effect of test ($F_{1, 22} = 14.73$, $p = 0.001$), with increased HT at the end of the bathing regimen. There was no effect of Group ($F < 1$) and no interaction ($F < 1$).

To summarise, Energetic Arousal and Hedonic Tone were higher at the end of the bathing regimen, but Tense Arousal remained unchanged. These effects occurred irrespective of the type of oil used, although Energetic Arousal was generally higher in the lavender group.

Table 11: Means and standard deviations (in parentheses) of mood scores during and around menstruation at the beginning and end of an aromatic bath series.

	Grapeseed (*n* = 20)		Lavender (*n* = 20)	
	Beginning	**End**	**Beginning**	**End**
Energetic Arousal (min. = 8, max. = 32)	19.50 (4.56)	22.33 (4.25)	20.25 (4.35)	26.75 (4.81)
Tense Arousal (min. = 8, max. = 32)	15.42 (4.10)	13.83 (3.33)	13.25 (6.55)	11.50 (4.10)
Hedonic Tone (min. = 8, max. = 32)	22.67 (5.66)	26.67 (4.68)	21.33 (7.36)	26.08 (5.55)

4.5.2.4 Discussion

The results demonstrate elevated Energetic Arousal and Hedonic Tone following a two-week bathing regimen in female participants tested during and around menstruation. These effects occurred irrespective of the oil used, supporting the findings of Morris (2002) that bathing alone improves mood state. More importantly, the present study showed that the mood-enhancing properties of bathing are also effective during a time where mood tends to be less positive. This has useful implications for maintaining psychological well-being in women.

Morris' additional findings that these benefits could be augmented by using lavender oil were not supported here; although the lavender group did display higher Energetic Arousal, this did not occur as a function of bathing and may represent sampling error. Alternatively, the borderline significance level suggests the possibility of Type II errors.

Interestingly, baseline Hedonic Tone scores were lower than those found in the original Morris (2002) study. Post-bathing scores were more comparable, albeit still slightly lower in the present study. This not only supports Study 4, which found Hedonic

Tone to be lower perimenstrually, but also suggests that bathing may help to alleviate some of the somatic discomfort associated with menstruation. This would fit Cockerill, Wormington and Nevill's (1994) assertion that there is a causal link between mood state and physical symptoms during menstruation.

The decrease in Tense Arousal found in the original Morris study was not replicated. Inspection of the means in Table 11 above, and Table 1 in Morris (2002) revealed that baseline Tense Arousal was actually lower in the present study; post-bathing scores were similar for both studies. Much of the menstrual cycle literature, especially that on the Premenstrual Syndrome (see section 1.3.4), would imply that this was unexpected; however, the menstrual cycle studies reported here (see Section 4.2) found few menstrual cycle-related effects on Tense Arousal. The present study fits the view put forward previously that perimenstrual mood tends to be less positive rather than more negative.

In conclusion, the results of this study provide some evidence for the efficacy of bathing *per se* as a means to enhance and improve mood state, even around menstruation where mood may be less positive. These results should be interpreted with a degree of caution, as the improvement in mood could in part be due to differences in cycle phase from the first to second test. Nevertheless incorporating a relaxing bath into one's daily routine, particularly during the perimenstruum, may help maintain a calm-energetic mood state, which can provide a useful defence against oncoming stressors.

4.5.3 Study 12: Effects of chocolate with differing carbohydrate content on perimenstrual blood glucose, memory and mood.

4.5.3.1 Introduction

The mood-enhancing properties of chocolate, particularly around menstruation, have been eulogised throughout popular science and women's lifestyle publications. Whilst a number of reasons have been put forward for this phenomenon, one of the most common (and perhaps most logical) is that the sugar content of chocolate exerts its effects on mood by raising blood glucose levels. This study applies this principle to the context of the working day, testing the effects of chocolate on blood glucose levels, mood and memory performance in women in the premenstrual to menstrual phases of their cycles.

As demonstrated in a previous study series (see Section 4.3), raising blood glucose levels not only enhances positive mood, but also facilitates coping with the demands of a cognitive task even where performance is not affected directly. In addition, evidence for menstrual cycle-related changes in glycaemic control (see section 1.2.5; also see Study 10, 4.4.3) suggests that blood glucose may be a mediating factor in the mood fluctuations associated with the menstrual cycle.

An important consideration arising from the findings of the previous study series (see section 4.4) is that individuals will 'self medicate' throughout the day in order to counteract natural low points in blood glucose levels and mood. It is a common stereotype that, among premenstrual and menstruating women, the self-administered 'medication' of choice tends to be chocolate. Whilst the amelioration of low blood glucose levels during this time has long been postulated as a reason for craving chocolate and other sweet foods (Ottley, 2000; Bowen & Grunberg, 1990; Dalton, 1987) an

alternative hypothesis is that it is simply the desire to reduce appetite and improve mood by eating something pleasant-tasting (Vlitos & Davies, 1996; Barr *et al.*, 1995; Hill & Heaton-Brown, 1994). In other words, craving chocolate or sweets is not a response to a specific nutritional need, i.e. carbohydrates. A more detailed review can be found in **1.2**.

Another point to consider is the manner in, and extent to which, blood glucose levels are raised. Despite the apparent benefits of ingesting almost instantaneous sources of glucose, such as the drinks used in the study series reported in section 4.3, such 'quick fixes' cannot be recommended as regular practice. Repeated 'spiking' of blood glucose levels, as discussed previously (see sections 1.2.and 4.3.5), has potentially detrimental consequences for mood, cognition and long-term health. Furthermore, ideal blood glucose levels for optimum cognitive functioning are moderate (5.5 – 7.2 mmol/l) rather than high (Bellisle, 2002). In terms of practicality, glucose drinks such as those used previously are not only relatively unpalatable, but because of this are unlikely to be consumed as a snack in a real-life situation.

Chocolate, on the other hand, is more palatable and readily accessible, and has the added benefit of having a lower glycaemic index than pure glucose due to its fat content slowing the absorption of sugars into the bloodstream. A full explanation of this process is given in section 1.2.2. To compare the effects of differing carbohydrate content on mood and cognition, two kinds of chocolate were used: Tesco milk chocolate and Boots 'LoCarb' chocolate. These were matched as closely as possible for their calorie, protein and fat content, but differ in their carbohydrate composition. Simple sugars are the main source of carbohydrate in the Tesco milk chocolate, whereas in the Boots LoCarb chocolate, polyols (namely maltitol, lactitol and sucralose) are the predominant source.

Polyols are sugar-free sweeteners which are derived from sugars, but not processed by the body like sugars. Instead, they are slowly and incompletely absorbed from the small intestine into the blood. The portion that is absorbed is metabolised by processes requiring little or no insulin, thus causing smaller increases in blood glucose and insulin levels than do sugars and other carbohydrates. Polyols also have a reduced number of calories compared to sugars.

A recent study by Morris (2008) showed that both types of chocolate caused blood glucose levels to increase, but within an hour blood glucose returned to normal, indicating good glucose tolerance to both chocolate types. There was also a marked and persistent decrease in Tense Arousal, which demonstrates that it is possible to reduce perceived tension by consuming a snack that does not raise blood glucose beyond normal levels.

The present study sought to extend these findings, and apply them specifically to the management of perimenstrual mood during the working day. Participants had their blood glucose levels, mood state and memory recall assessed before and approximately an hour following the ingestion of either Tesco milk chocolate or Boots LoCarb chocolate. As with the earlier studies using glucose and saccharine, they were not aware that there was a distinction – to ensure comparability, the palatability of both chocolates was also measured. Recall was assessed using a video presentation designed to inform students about safety issues; this was the same video used in Study 7 (see section 4.3.3), and was utilised for the same reason of salience to the study sample. Considering Morris' (2008) findings alongside those of the previous study series, it was expected that:

1) A chocolate snack could be used to raise blood glucose levels and improve memory and mood (as defined by increased Energetic Arousal and Hedonic Tone and reduced Tense Arousal);

2) These effects would possibly be more pronounced in the group receiving Tesco milk chocolate as opposed to Boots LoCarb;

3) These effects would be reduced, or even absent among oral contraceptive users.

4.5.3.2 Method

4.5.3.2.1 Participants

28 female undergraduate students aged 19 to 38 years (mean age = 22.46, s.d. = 5.92) took part in this study as part of a research methods workshop. All participants were either in the week before or during menstruation; 14 were oral contraceptive users and 14 had natural menstrual cycles. Exclusion criteria included pregnancy, diabetes mellitus, haemoplilia, heart or respiratory conditions, and allergies to chocolate or nuts. All participants had eaten a light breakfast (roughly calculated to be < 500 kcal from the information given at the beginning of the study); none had fasted.

4.5.3.2.2 Materials

Mood was measured using the UWIST Mood Adjective Checklist (UMACL; see section 3.3.1 for details of scoring and administration). Following a verbal briefing on the nature and requirements of the study participants signed an informed consent form (Appendix B12.1). They also completed a questionnaire requiring them to itemise and quantify their breakfast that morning (Appendix B12.2) and a menstrual questionnaire containing

questions on age, parity, contraception and date of last menstrual period (LMP; Appendix B12.3). Participants were also issued with a menses onset slip (see Appendix B12.4) to provide the date of their next menstrual period; this was linked to their data by a unique number, which did not appear on the consent form. The equipment used for blood glucose testing was identical to that described in Study 6 (see section 4.3.2.2.2). Each participant was provided with written instructions for blood sampling, which included a table in which to record their readings (Appendix B12.5).

Memory recall was assessed using a video on safety awareness, in which the content was summarised in a number of bulletin points at the end of each video. The video was entitled, 'A Sixth Sense' (EagleEye Productions Video (2000) cat. No. EE9569) and had been edited in order to produce Tape A and Tape B. Details of content and scoring can be found in section 4.3.3.2.2. Response sheets reproducing the outline of the video were provided for recall (see Appendix B12.6). The order of viewing was counterbalanced so that half the participants viewed Tape A first (i.e. before the chocolate) and the other half viewed Tape B first. This was to eliminate any possible confounding effects of one tape being easier to recall than the other.

Participants consumed approximately 38g of Tesco milk chocolate or 40g of Boots LoCarb chocolate. The slight difference in exact quantities was in order to match the two types of chocolate for calorific content. Nutritional values per 100g of each product are provided in Table 12a.

Table 12a: Nutritional values (per 100g) for the Tesco Milk Chocolate and Boots LoCarb Chocolate.

	Tesco Milk Chocolate	Boots LoCarb Chocolate
Energy	2,216KJ (531Kcal)	2,031KJ (485Kcal)
Protein	7.3g	7.0g
Carbohydrate	55.6g	44.0g
- of which sugars	54.9g	9.0g
- of which polyols	Unknown	34.0g
Fat	31.0g	38.0g
- of which saturates	18.5g	24.0g
Fibre	1.9g	8.0g
Sodium	0.1g	0.1g

4.5.3.2.3 Procedure

The experiment took place over four days, with each session taking place at the same time each day. Table 12b shows the combination of chocolate type and order of video presentation for each session. Different chocolates were given on different days so that participants would not be aware that there were two groups. Subdividing the groups further enabled counterbalancing of tapes A and B.

Table 12b: Type of chocolate consumed and order of video presentation within each experimental session.

Session	Chocolate type	Video viewed first
1	LoCarb	Tape A
2	LoCarb	Tape B
3	Tesco	Tape B
4	Tesco	Tape A

Firstly participants were briefed on the nature of the study, with a full demonstration of the procedure for blood sampling. Informed consent was given and the breakfast questionnaire was completed. Baseline blood glucose levels were obtained at approximately 10:30 a.m. Two readings were taken and the average calculated to give a more accurate measure. The first UMACL was completed, followed by the viewing of the first video. After the video, participants were asked to recall as many of the bulletin points as they could.

Following the recall task, participants consumed 40g of either Boots LoCarb or Tesco Milk chocolate. In order to determine whether the two chocolate samples were perceived to be significantly different in taste, participants were asked to rate its palatability on a scale of 1 – 'it was delicious' to 5 – 'it was horrible' (see Appendix B12.6). If the entire chocolate sample was not consumed, participants were asked to indicate this by circling 0 – 'I didn't eat the chocolate'; their data were excluded from statistical analyses. Participants were then given a 20 minute break in order for their bodies to begin absorbing the chocolate. They were asked not to consume any food or drinks containing sugar so that any subsequent change in blood glucose levels could be attributed to consumption of the chocolate.

After the break, in order to allow more time for the metabolism of the chocolate, participants were shown a 25 minute DVD of an interview with Eric Schlosser (one of the special features accompanying the film 'Super Size Me'). Approximately 50 minutes after chocolate consumption (around 12.10 p.m.), participants gave a second blood glucose reading and completed the second UMACL. The second half of the safety video

was then viewed (approximately 70 minutes after chocolate consumption), followed by recall of the bulletin points shown at the end.

At around 12:50 p.m. (around 90 minutes after chocolate consumption) blood glucose was measured for the third and final time, followed by completion of the UMACL. Participants also completed a menstrual questionnaire, and were asked to provide the date of their subsequent menstrual period so that the phase defined by the date of their last period could be confirmed. This was done by simply writing the date on the menses onset slip and posting it in an envelope left outside the researcher's office. All slips returned confirmed that testing took place during the premenstrual to menstrual phases. Participants were debriefed two weeks later.

4.5.3.3 Results

Blood glucose levels and scores on each dimension of the UMACL were entered into 3 x 2 x 2 mixed design analyses of variance (ANOVA), with Test (before, 50 minutes after and 70 minutes after the chocolate) as the within-subject factor. The between-subjects factors were Group (Tesco/LoCarb) and oral contraceptive (OC) use (user/non-user).

For blood glucose there was no effect of Test ($F_{2, 48} = 2.21$ $p > 0.05$), no effect of Group ($F_{1, 24} = 2.31$, $p > 0.05$) and no effect of OC ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and OC ($F < 1$) or Group and OC ($F_{1, 24} = 1.93$, $p > 0.05$), nor was there a three-way interaction between Test, Group and OC ($F < 1$). Means and standard deviations can be found in Table 12c.

Table 12c: Means and standard deviations (in parentheses) for blood glucose levels (mmol/l) before and after consuming Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use.

	Test 1 (Before)		Test 2 (50 mins after)		Test 3 (90 mins after)	
	LoCarb	Tesco	LoCarb	Tesco	LoCarb	Tesco
OC users	4.90 (0.92)	4.98 (0.48)	5.22 (0.63)	5.21 (1.03)	4.74 (1.38)	4.76 (0.73)
Non-users	4.48 (0.79)	5.28 (0.56)	4.76 (0.84)	5.70 (1.06)	4.79 (0.85)	5.11 (0.53)
All	4.69 (0.85)	5.13 (0.52)	4.99 (0.75)	5.45 (1.03)	4.76 (1.10)	4.94 (0.64)

For Energetic Arousal (EA) there was no effect of Test ($F < 1$), no effect of Group ($F < 1$) and no effect of OC ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and OC ($F < 1$) or Group and OC ($F < 1$). There was, however, a significant three-way interaction between Test, Group and OC ($F_{2, 48} = 6.83$, $p < 0.01$). *Post hoc* analysis was carried out by performing separate 3 x 2 ANOVAs on the two OC groups (OC users and naturally cycling women), followed by simple effects analysis. Figure 10 illustrates the three-way interaction. EA decreased by the third test after consuming the LoCarb chocolate, but only in naturally cycling women. Despite baseline differences between groups, OC users did not differ in EA after consuming either type of chocolate. Means and standard deviations can be found in Table 12d.

Table 12d: Means and standard deviations (in parentheses) for Energetic Arousal scores before and after consuming Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use. Min. = 8, Max. = 32.

	Test 1 (Before)		Test 2 (50 mins after)		Test 3 (90 mins after)	
	LoCarb	**Tesco**	**LoCarb**	**Tesco**	**LoCarb**	**Tesco**
OC users	18.14 (3.24)	22.00 (4.20)	21.00 (4.83)	20.57 (3.65)	20.71 (5.71)	19.57 (4.20)
Non-users	22.00 (3.00)	19.57 (6.45)	20.57 (3.16)	21.57 (4.20)	19.29 (2.87)	22.00 (2.50)
All	20.07 (3.61)	20.79 (5.40)	20.79 (3.93)	21.07 (3.81)	20.00 (4.40)	20.79 (3.53)
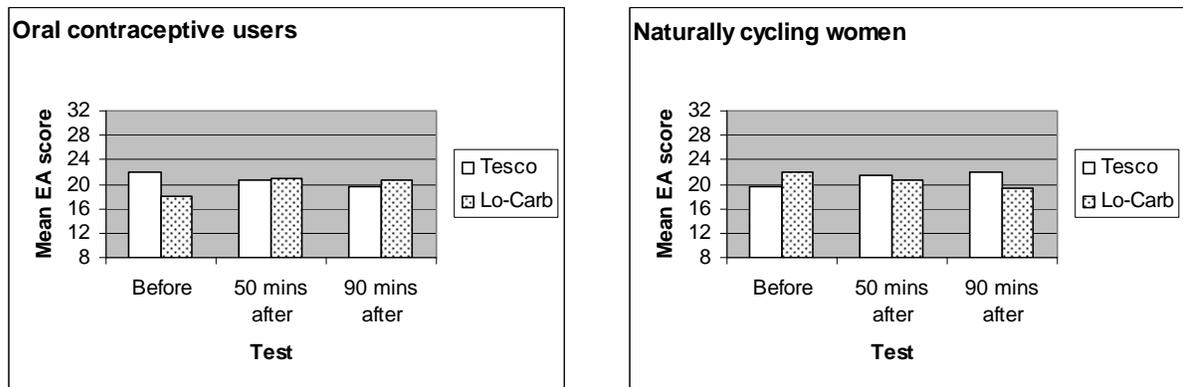
Figure 10: 3-way interaction between test time, type of chocolate consumed and oral contraceptive use on Energetic Arousal.

For Tense Arousal (TA) there was a significant main effect of Test ($F_{2, 48} = 23.96$, $p < 0.001$). *Post hoc* paired *t*-tests with a Bonferroni correction revealed that TA was lower 50 minutes after the chocolate, and that this effect was still present 90 minutes after consumption. There were no effects of either Group ($F < 1$) or OC ($F < 1$), no interactions between Test and Group ($F < 1$), Test and OC ($F < 1$) or Group and OC ($F < 1$), nor was there a three-way interaction between Test, Group and OC ($F < 1$). TA was

lower after the chocolate had been consumed, but this occurred irrespective of the type of chocolate or oral contraceptive use. Means and standard deviations can be found in Table 12e.

Table 12e: Means and standard deviations (in parentheses) for Tense Arousal scores before and after consuming Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use. Min. = 8, Max. = 32.

	Test 1 (Before)		Test 2 (50 mins after)		Test 3 (90 mins after)	
	LoCarb	Tesco	LoCarb	Tesco	LoCarb	Tesco
OC users	18.00 (3.27)	18.29 (5.25)	15.00 (1.73)	14.43 (3.36)	15.14 (2.61)	14.14 (2.27)
Non-users	17.86 (3.49)	18.00 (5.89)	13.86 (3.53)	12.71 (3.15)	13.86 (2.73)	13.71 (2.36)
All	17.93 (3.25)	18.14 (5.36)	14.43 (2.74)	13.57 (3.25)	14.50 (2.65)	13.93 (2.24)

For Hedonic Tone (HT) there was no effect of Test ($F < 1$), no effect of Group ($F < 1$) and no effect of OC ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and OC ($F < 1$) or Group and OC ($F < 1$), nor was there a three-way interaction between Test, Group and OC ($F < 1$). Means and standard deviations can be found in Table 12f.

Table 12f: Means and standard deviations (in parentheses) for Hedonic Tone scores before and after consuming Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use. Min. = 8, Max. = 32.

	Test 1 (Before)		Test 2 (50 mins after)		Test 3 (90 mins after)	
	LoCarb	Tesco	LoCarb	Tesco	LoCarb	Tesco
OC users	24.57 (3.16)	26.00 (2.31)	25.86 (4.30)	25.86 (2.91)	24.14 (5.21)	26.14 (2.27)
Non-users	26.00 (2.94)	25.43 (3.99)	26.29 (2.69)	24.71 (3.95)	25.71 (2.63)	24.71 (2.69)
OC users	25.29 (3.02)	25.71 (3.15)	26.07 (3.45)	25.29 (3.38)	24.93 (4.05)	25.43 (2.50)

The number of bulletin points correctly recalled from the video was converted to a percentage and then entered into a 2 x 2 x 2 mixed design ANOVA, with Test (before vs. 50 minutes after the chocolate) as the within-subject factor. The between-subjects factors were Group (Tesco/LoCarb) and oral contraceptive (OC) use (user/non-user). There was no effect of Test ($F < 1$), no effect of Group ($F < 1$) and no effect of OC ($F < 1$). There were no interactions between Test and Group ($F < 1$), Test and OC ($F < 1$) or Group and OC ($F_{1, 24} = 3.35$, $p > 0.05$), nor was there a three-way interaction between Test, Group and OC ($F_{1, 24} = 1.84$, $p > 0.05$). Means and standard deviations can be found in Table 12g.

Table 12g: Means and standard deviations (in parentheses) for % of bulletin points correctly recalled from a video on safety before and after consuming Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use.

	Test 1 (Before)		Test 2 (50 mins after)	
	LoCarb	**Tesco**	**LoCarb**	**Tesco**
OC users	72.40 (15.83)	69.33 (15.89)	75.70 (12.64)	68.20 (12.22)
Non-users	67.23 (11.03)	70.01 (11.85)	63.40 (10.84)	78.63 (14.21)
All	69.81 (13.38)	69.67 (13.47)	69.55 (12.99)	73.41 (13.84)

Ratings of chocolate palatability were entered into a 2 x 2 between-subjects ANOVA, with Group (Tesco/LoCarb) and oral contraceptive (OC) use (user/non-user) as the factors. There was a significant main effect of Group ($F_{1, 24} = 9.92$, $p < 0.01$), with the LoCarb chocolate being rated as more palatable overall, but no effect of OC ($F < 1$). There was, however, a significant interaction ($F_{1, 24} = 7.84$ $p = 0.01$). Figure 11 illustrates this interaction: simple effects analysis revealed that this was due to a marked preference for the LoCarb chocolate among oral contraceptive users only ($p < 0.01$). Non-users did not differ in their ratings of the two types of chocolate. Thus, the LoCarb chocolate was perceived as being more palatable than the Tesco Milk chocolate, but only by oral contraceptive users. Means and standard deviations can be found in Table 12h.

Table 12h: Means and standard deviations (in parentheses) for ratings of the palatability of Boots LoCarb or Tesco milk chocolate, stratified by oral contraceptive use. Min. = 1, max. = 5.

	LoCarb	Tesco
OC users	3.86 (1.22)	1.43 (0.79)
Non-users	2.57 (0.98)	2.43 (1.27)
All	3.21 (1.25)	1.93 (1.14)
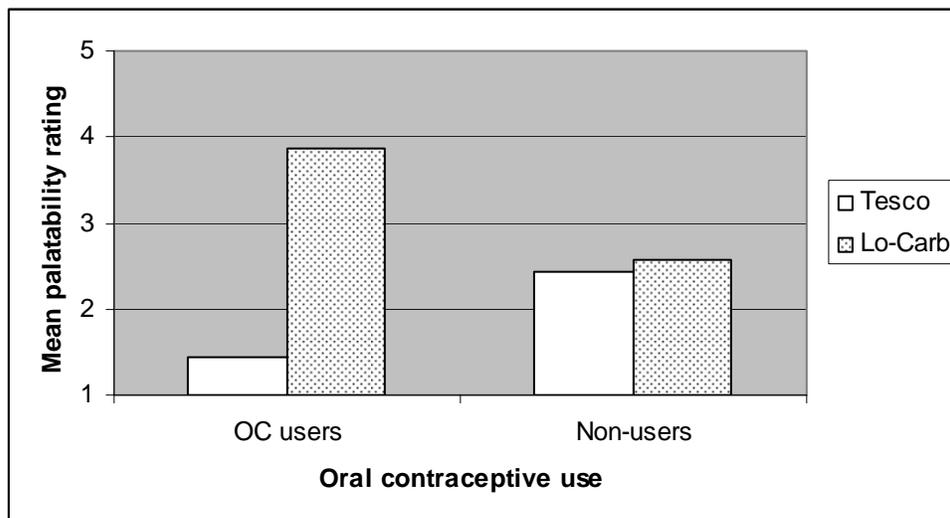
Figure 11: Interaction between type of chocolate consumed and oral contraceptive use on mean ratings of chocolate palatability.

To summarise, blood glucose levels were unchanged both 50 and 90 minutes following consumption of either type of chocolate, and did not vary as a function of oral contraceptive use. Similarly, the amount of information recalled from the video presentation was not affected by either chocolate consumption or oral contraceptive use. However, Energetic Arousal was significantly lower following the LoCarb chocolate in

naturally cycling women only. Tense Arousal was lower following both types of chocolate, irrespective of oral contraceptive use; this effect was still present 90 minutes following consumption. Hedonic Tone was unaffected by both chocolate consumption and oral contraceptive use. The LoCarb chocolate was generally perceived as being more palatable than the Tesco Milk chocolate; this preference was only apparent among oral contraceptive users.

4.5.3.4 Discussion

Neither blood glucose levels nor the amount of information correctly recalled from the safety presentation varied as a function of chocolate ingestion or oral contraceptive use. However, despite blood glucose levels remaining unchanged both 50 minutes and 90 minutes following chocolate consumption, perceived tension (as measured by the Tense Arousal subscale) was significantly reduced at both time points. Oral contraceptive use also appeared to have some impact upon mood state, as Energetic Arousal (EA) was reduced following the LoCarb chocolate in women with natural menstrual cycles despite no difference in chocolate preference among this group. Conversely, oral contraceptive users showed a marked preference for the LoCarb chocolate.

The fact that blood glucose levels did not vary across the three time points does not mean that they were not raised by the chocolate; more likely, the chocolate had already been metabolised by the time 50 minutes had passed so that blood glucose had returned to baseline levels. This would demonstrate good glucose tolerance to both types of chocolate snack, as shown by Morris (2008); this is indeed what would be expected within a relatively young and healthy sample (Bellisle, 2002).

The reduction in perceived tension, which persisted 90 minutes following chocolate consumption, suggests that this was the case and supports the findings of Morris (2008). It also extends these findings by showing that they can be generalised to women in the premenstrual and menstrual phases of their cycle, where mood is likely to be less positive. This has important implications in terms of interventions for maintaining a positive mood state; it demonstrates that it is not only possible to reduce tension without raising blood glucose beyond normal levels, but also that a snack containing fewer simple sugars does this just as effectively as a high-sugar snack.

As with Study 7 (see section 4.3.3), ingesting more simple carbohydrate did not lead to increased recall. Unlike Study 7, however, there was no improvement even from the first to second test. One explanation may be that there was a ceiling effect; in the present study recall was already high even on the first test, and was considerably higher than in Study 7. Alternatively, it may be the case that even though a chocolate snack might not enhance memory function, it can help maintain it. Again, this has useful implications for performance in the workplace, and subsequent mood response. The reduction in tension despite no improvement in performance supports previous studies (see section 4.3) demonstrating that maintaining stable blood glucose levels can improve the way in which individuals respond to tasks with high cognitive demand. Furthermore, it again shows that such interventions are also effective during the perimenstruum.

Nevertheless, the role of oral contraceptives complicates this somewhat and needs to be considered. In women with natural menstrual cycles, EA was reduced 90 minutes following chocolate consumption in the LoCarb group. The fact that this occurred even though they rated the two types of chocolate as equally palatable suggests that it is a

physiological function of the sugar content rather than a psychological function of the taste. This would fit the view that chocolate cravings during the perimenstruum are driven by a need to ameliorate low blood glucose at this time (Ottley, 2000; Bowen & Grunberg, 1990; Dalton, 1987), particularly as oral contraceptive users showed no such difference. Moreover, oral contraceptive users actually preferred the LoCarb chocolate. Whilst this may suggest that they found the Tesco Milk chocolate too sweet due to not needing more sugar, the fact that they experienced no change in EA also reinforces the contradiction of the 'taste' hypothesis.

To conclude, these findings extend those of Morris (2008) by indicating that a chocolate snack can be used to maintain cognitive performance and reduce perceived tension without raising blood glucose beyond the normal range, even during the premenstrual and menstrual phases. Chocolate that is relatively low in simple sugars is just as effective in doing this, suggesting that it is the maintenance rather than the increasing of blood glucose levels that is important. Nevertheless, the reduction in perceived energy among women with natural menstrual cycles indicates that during this time women may be more vulnerable to changes in blood glucose and subsequent mood. Steps should be taken to ensure that blood glucose is maintained at optimal levels so that mood state is not impaired during this time.

4.5.4 Summary of intervention studies

These two studies demonstrate two simple yet effective interventions for maintaining a positive mood state during the perimenstruum. As proposed by Martino and Morris (2004), taking relatively minor ergonomic 'steps' as part of one's everyday routine can

help to prevent or ameliorate negative moods; moods which might otherwise lead to the development of stress and eventually more pathological states. Study 11 shows that taking a daily bath to provide such 'downtime' will eventually set baseline mood at a more calm-energetic level (see Thayer, 2001). Study 12 follows on from the previous study series (see sections 4.3 and 4.4) to demonstrate the importance of maintaining stable blood glucose levels throughout the working day, particularly around menstruation where women may be more vulnerable to the effects of low blood glucose on mood. The findings also highlight the need to take into account oral contraceptive use in studies of menstrual cycle effects on mood, and the importance of considering such factors in attempting to develop interventions for promoting a state of calm-energy.

5. SUMMARY OF OVERALL RESULTS

Studies were carried out as distinct series to address different components of the research question individually, and in relation to one another to bring together the various factors involved. The first study series (section 4.1) was designed to establish diurnal changes in mood and to consider these effects within a working context.

Study 1 was a simple 'diary'-type study to investigate fluctuations in mood during individuals' normal, everyday routines; sex was brought in as a factor by means of a preliminary stage for examining a possible menstrual-circadian interaction in later studies. Mood ratings were compared between males and females for the morning, afternoon and evening. Only Energetic Arousal varied significantly across the day, peaking in the afternoon and showing a selective dip in the evening for females. There were no effects of either time of day or sex on Tense Arousal or Hedonic Tone. Energetic Arousal corresponded to more positive mood across the day, namely increased Hedonic Tone. Conversely, increased Tense Arousal corresponded to more negative mood, namely decreased Hedonic Tone. Increased Energetic Arousal corresponded to decreased Tense Arousal in the afternoon and evening.

Study 2 measured mood states before and after a research methods workshop, comparing groups tested either in the morning or in the afternoon. Mood was generally more negative and less positive following the research methods workshop, with increased levels of Tense Arousal and reduced Hedonic Tone post-workshop. Hedonic Tone was also generally lower in the afternoon group. The afternoon group experienced a selective reduction in Energetic Arousal post-workshop.

Having established that diurnal fluctuations in mood were influenced by both sex and situations requiring cognitive effort, the next stages were to a) consider the role of the menstrual cycle in determining mood state, b) examine how the menstrual cycle might interact with the time of day, and c) investigate the physiology underlying the apparent effects of a cognitive/working situation. The first two points were addressed by the second study series in section 4.2.

Study 3 simply compared mood states across three points in the menstrual cycle (menstrual, midcyle and premenstrual), again using a diary format so that participants could record their everyday moods within their normal routines. Only Energetic Arousal varied significantly across the menstrual cycle, reaching its lowest point during menstruation. Tense Arousal and Hedonic Tone did not differ between the menstrual, mid-cycle and premenstrual phases. Given that the group consisted mainly of oral contraceptive users, this was noted as potentially important for further studies.

Study 4 tested participants weekly at set points, using onset of menses to retrospectively determine cycle phase. Taking into account the literature, and the findings from Study 3, phases were grouped into the perimenstruum, consisting of the premenstrual and menstrual phases where mood was hypothesised to be less positive, and the mid-cycle. Both within- and between-subject comparisons were made to assess the appropriateness of having cycle phase as a between-subjects factor in subsequent studies. When making within-subjects comparisons, mood was generally more positive midcycle compared to the perimenstruum, with increased Energetic Arousal and Hedonic Tone. Tense Arousal was unaffected by cycle phase. These effects were replicated when

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menstrual cycle phase was grouped as a between-subjects factor, indicating robustness of mood effects as well as confirming the viability of between-subject phase comparisons.

Study 5 looked at menstrual cycle-related fluctuations in mood in greater detail, extending the diary format of Study 3 to measure mood over 28 consecutive days. Moreover, this study addressed two of the issues raised by previous studies: the possible menstrual-circadian interaction, and the effects of oral contraceptive use. Initial analysis of trends across all 28 days of the menstrual cycle indicated that mood was generally more positive in the midcycle days, characterised by increased Energetic Arousal and decreased Tense Arousal compared with the days prior to and immediately following menstruation. When broken down to compare the menstrual, midcycle and premenstrual phases (within-subjects) and the morning, afternoon and evening (between-subjects), no effects were found: neither menstrual cycle phase nor time of day were found to have an effect on Energetic Arousal, Tense Arousal or Hedonic Tone. However, when broken down further to compare oral contraceptive users with non-users, women with natural menstrual cycles demonstrated increased Energetic Arousal in the afternoon during the follicular and ovulatory (midcycle) phases only. By contrast, women taking oral contraceptives showed no mood variations at all. Thus a menstrual-circadian interaction on mood was found only in naturally cycling women, and only for Energetic Arousal.

The third study series (section 4.3) focused on the physiology underpinning overall mood, and the effects of a cognitively demanding/working context. The aim was to expand upon and answer the questions raised by the first study series.

Study 6 compared mood states before and after a glucose drink or saccharine-based placebo, demonstrating how mood can be directly manipulated by altering blood

glucose levels. Both blood glucose levels and positive mood increased following a glucose drink but not following a saccharine drink; Energetic Arousal and Hedonic Tone were significantly increased and Tense Arousal decreased following the glucose drink but not the placebo.

Study 7 looked specifically at mood and stress-related responses (using the Dundee Stress State Questionnaire: DSSQ) to a cognitively demanding task (in this instance memory recall), with and without ingesting glucose. Again, blood glucose levels were significantly raised by ingesting a glucose drink, but not a saccharine drink. Memory recall was significantly higher on the second test irrespective of the drink consumed. The two groups did not differ in baseline scores on any dimension of the DSSQ at the start of the study. However, those who had ingested glucose experienced significantly lower Tense Arousal, Self-Focused Attention, Task-Related Interference and Task-Irrelevant Interference, and significantly higher Hedonic Tone and Concentration whilst completing the task for the second time compared to those who had ingested saccharine. Energetic Arousal, Anger-Frustration, Motivation, Self-Esteem, Control & Confidence and perceived Workload did not differ according to the drink imbibed. Thus, whilst raising blood glucose levels did not facilitate recall, it reduced stress response to the task on specific dimensions.

Study 8 followed on from Study 7 to consider other factors in mood response to cognitive tasks, this time using the Stroop task as this was known to have both cognitive and affective demands. In addition to mood, anxiety was included as both a factor and dependent variable; not only were the effects of the task and glucose ingestion on State Anxiety measured, but the effects of Trait Anxiety were also taken into account.

Furthermore, groups tested either in the morning or afternoon were compared to identify any diurnal effects on either blood glucose or mood. Initial analysis revealed that blood glucose levels were significantly raised following a glucose drink but not a saccharine drink, with a greater increase for participants tested in the morning. These participants also had higher blood glucose levels overall compared with those tested in the afternoon. Energetic Arousal was significantly higher and State Anxiety significantly lower following the Stroop task, but this occurred irrespective of the drink consumed or the time of day. Tense Arousal and Hedonic Tone were not affected by the task, the type of drink consumed or the time of day; nor was the time taken to complete the Stroop task. Errors made on the task were significantly lower among participants who had consumed a glucose drink, but this was again irrespective of the time of day.

Including Trait Anxiety as a covariate revealed that higher Trait Anxiety was associated with greater Tense Arousal and State Anxiety and lower Hedonic Tone both before and after performing the Stroop task. Once the effects of Trait Anxiety had been partialled out, there were no effects of either the task, the type of drink consumed or the time of day on Energetic Arousal, Hedonic Tone, State Anxiety, the time taken to complete the Stroop task or the number of errors made. Tense Arousal was significantly lower following a glucose drink for participants tested in the morning. These effects occurred irrespective of testing time in relation to the task.

Thus, blood glucose levels tended to be higher in the morning compared with the afternoon, and were significantly raised following a glucose drink but not a saccharine drink, with a more pronounced increase for participants tested in the morning. Energetic Arousal was significantly higher and State Anxiety lower following the task, irrespective

of the drink consumed or the time of day; however, when the effects of Trait Anxiety were partialled out these effects were no longer present. Conversely, Tense Arousal initially showed no effects of the task, the type of drink consumed or the time of day, but partialling out the effects of Trait Anxiety revealed that TA was lower following a glucose drink for participants tested in the morning. The initial analysis also indicated fewer errors on the Stroop task following a glucose drink, although this effect also disappeared on partialling out Trait Anxiety. Hedonic Tone and the time taken to complete the Stroop task did not vary from pre- to post task, with the drink consumed or the time of day, with or without Trait Anxiety as a covariate. Higher Trait Anxiety corresponded to higher Tense Arousal and State Anxiety and lower Hedonic Tone both pre- and post-task. Overall, mood and anxiety responses to the Stroop task appear to be moderated by Trait Anxiety.

The fourth study series (section 4.4) concentrated in greater depth on the apparent diurnal effects on both mood and blood glucose levels. The menstrual cycle was brought in as a factor so that the menstrual-circadian interaction identified in the second study series might be explained, at least partially, in terms of changes in blood glucose.

Study 9 involved hourly self-testing of blood glucose levels and mood for 12 consecutive hours. Overall, a higher blood glucose level was associated with greater Energetic Arousal and Hedonic Tone, but was unrelated to Tense Arousal. These effects remained even after controlling for the time of day. Energetic Arousal was lower in the morning compared with the afternoon and early to late evening, but neither blood glucose levels nor any of the other mood dimensions showed significant diurnal variations.

Study 10 was a direct follow-up to Study 9 with the same methodology, except that participants were specifically women in the premenstrual to menstrual phases of the menstrual cycle. This time no association was found between blood glucose levels and mood, although Energetic Arousal was still lower in the morning. However, an evening peak in Energetic Arousal was also found, as well as corresponding trends in Tense Arousal and Hedonic Tone. In other words, among women in the perimenstruum (most of whom were not oral contraceptive users) mood was more tense-tired and less pleasant in the morning, and more calm-energetic and pleasant in the evening. It appears that diurnal fluctuations in mood are influenced, and even exacerbated, in the premenstrual to menstrual phases, although these fluctuations are not necessarily negative.

The fifth and final study series (section 4.5) utilised the findings of the previous study series to suggest practical ways to maintain a positive mood state during times that were more vulnerable to negative mood changes: specifically, the perimenstruum.

Study 11 tested the effects of a two-week bathing regimen on perimenstrual mood state, using either grapeseed oil (a neutral base oil) or a blend of lavender and grapeseed oils. Energetic Arousal and Hedonic Tone were higher at the end of the bathing regimen. Tense Arousal remained unchanged. These effects occurred irrespective of the type of oil used, although Energetic Arousal was generally higher in the lavender group. Thus, mood was enhanced by the two-week bathing regimen, even during the premenstrual to menstrual phases.

Study 12 built upon the blood glucose-related findings of the two previous study series to examine the effects of ingesting a snack on mood response to a cognitive task (memory recall), focusing again on women in the premenstrual to menstrual phases. As

the aim was to suggest a practical intervention, different types of chocolate snacks were used in lieu of drinks: Tesco Milk chocolate, which is high in simple sugars, and Boots LoCarb chocolate, which contains fewer carbohydrates in simple sugar form. Blood glucose levels were unchanged both 50 and 90 minutes following consumption of either type of chocolate, and did not vary as a function of oral contraceptive use. Similarly, the amount of information recalled from a video presentation was not affected by either chocolate consumption or oral contraceptive use. However, Energetic Arousal was significantly lower following the LoCarb chocolate in naturally cycling women only. Tense Arousal was lower following both types of chocolate, irrespective of oral contraceptive use; this effect was still present 90 minutes following consumption. Hedonic Tone was unaffected by both chocolate consumption and oral contraceptive use. The LoCarb chocolate was generally perceived as being more palatable than the Tesco Milk chocolate; this preference was only apparent among oral contraceptive users.

Summarising all experimental findings:

- The most consistent results were in relation to the Energetic Arousal dimension. Energetic Arousal was shown to be influenced by both the menstrual cycle and the time of day, as well as an interaction between these two factors, and was consistently related to changes in blood glucose levels. Energetic Arousal also appeared to be more sensitive to the effects of the suggested interventions and oral contraceptive use.

- In most instances the changes observed in relation to the menstrual cycle were on the 'positive' mood dimensions (i.e. Energetic Arousal and Hedonic Tone).

- Diurnal changes in mood throughout the course of a normal day were more evident among women in their premenstrual to menstrual phases.

- Effects on the more 'negative' dimension (i.e. Tense Arousal) tended to come into play when cognitive tasks were concerned.

- Trait Anxiety was a mediating factor in how individuals responded to such tasks.

- Mood was closely related to blood glucose levels, and raising blood glucose to a robust but safe level effectively enhanced positive mood.

- Oral contraceptives generally tended to eliminate menstrual cycle-related effects on mood and responses to intervention.

- Mood-enhancing interventions, namely aromatherapy baths and chocolate, can be effective in enhancing and/or maintaining a positive mood state during the perimenstruum.

Table 13 summarises the factors tested in each of the studies, indicating where there were effects on each of the three mood dimensions. It is important to acknowledge that some of these studies had small sample sizes due to their complexity; however, significance levels were in the main at the 1% or 0.1% level.

Table 13: Summary of effects across studies on the three principle subscales of the UWIST Mood Adjective Checklist: Energetic Arousal (EA), Tense Arousal (TA) and Hedonic Tone (HT).

Study	Factor (comparison/manipulation)	EA	TA	HT
1	Time of day	*		
	Sex			
	Interaction	*		
2	Time of day			*
	Pre-post task		*	*
	Interaction	*		
3	Menstrual cycle phase	*		
4	Menstrual cycle phase within-subjects	*		*
	Menstrual cycle phase between-subjects	*		*
5	Menstrual cycle – quadratic trends	*	*	
	Menstrual cycle phase			
	Time of day			
	OC use			
	*Interaction phase*time*			
	*Interaction phase*OC*	*		
	*Interaction time*OC*			
	*Interaction phase*time*OC*	*		
6	Glucose vs. Saccharine	*	*	*
7	Glucose vs. Saccharine post-task		*	*
8	Pre-post task	*		
	Time of day			
	Glucose vs. Saccharine			
	*Interaction test*drink*			
	*Interaction test*time*			
	*Interaction drink*time*			
	*Interaction test*drink*time*			
	Trait anxiety (covariate)		*	*
	Glucose vs. Saccharine (covariate partialled out)			
	Pre-post task (covariate partialled out)			
	Time of day (covariate partialled out)			
	*Interaction test*covariate*			
	*Interaction test*drink (covariate partialled out)*			
	*Interaction test*time (covariate partialled out)*			
	*Interaction drink*time (covariate partialled out)*		*	
	*Interaction test*drink*time (covariate partialled out)*			
9	Time of day	*		
	Blood sugar (correlation)	*		*

	Blood sugar (correlation, controlling for time of day)	*		*
10	Time of day	*	*	*
	Blood sugar (correlation)			
	Blood sugar (correlation, controlling for time of day)			
11	Pre-post bathing regimen Lavender vs. grapeseed oil	*		*
	Interaction			
12	Milk chocolate vs. LoCarb chocolate			
	Pre-post task		*	
	OC use			
	Interaction chocolate*test			
	Interaction chocolate*OC			
	Interaction test*OC			
	Interaction test*chocolate*OC	*		

6. GENERAL DISCUSSION

6.1 Overview of results

Considering the results as a whole, the broader hypotheses set out in section 2.2 are largely supported. Firstly, it was hypothesised that mood would vary both diurnally and across the menstrual cycle, with a possible interaction. This was found to be the case, with the interaction taking the form of an exacerbation of diurnal mood changes at certain phases of the menstrual cycle. Secondly, it was expected that mood would be associated with blood glucose levels – specifically, low blood glucose would be linked to more negative mood. This too was upheld, although context was an important factor; blood glucose appeared to play a role in how participants responded within cognitively demanding settings, which was in keeping with the third hypothesis. Finally, it was anticipated that the suggested interventions would have a positive effect on mood around and during menstruation. This hypothesis was also supported, with some evidence that these interventions could help improve or at least maintain perimenstrual mood.

6.2 Circadian rhythm effects on mood

From an applied perspective these findings have important implications for the management of mood throughout the working day. There was some evidence supporting Thayer's (e.g. 2001) 'typical' pattern of mood; Study 2 (4.1.3) found that Hedonic Tone (HT) was lower among participants tested in the afternoon compared with those tested in the morning. Moreover, response to a cognitive task or situation requiring relatively high

cognitive demand also appeared to be less positive in the afternoon, with the afternoon group experiencing a selective decrease in Energetic Arousal (EA) following a research methods workshop.

From a pure research perspective, however, the present study findings relating to diurnal changes in mood are of limited value. This is because variations in mood throughout the day are likely to be confounded by a number of extraneous factors, most notably food intake. Indeed, the afternoon reduction in positive mood, following the 'typical' pattern (Thayer, 1989), is often referred to as the 'post-lunch dip' for that very reason; reductions in energy and vigour are the by-product of digestion.

The HT scale itself important in terms of assigning valence to observed mood shifts and differences. As explained in section 1.2.1, it is difficult to label arousal states as 'positive' or 'negative'. A two-dimensional model of mood cannot distinguish between situations where, for example, an increase in tension might be beneficial – for example, the start of a race. Similarly, a decrease in energy might be a positive mood shift if it occurs just before bedtime. The inclusion of HT, which provides a measure of the overall pleasantness of mood and associated somatic comfort, adds greater depth to Thayer's four 'basic' moods. Considering the findings of Study 2 within this three-dimensional framework, the fact that lower HT in the afternoon group accompanied reduced post-workshop EA suggests that mood was less pleasant among these participants, or at least that these participants were more vulnerable to negative mood shifts.

Interestingly, some of the studies actually found some mood dimensions to be less positive in the morning, contradicting the expected trend. Study 1 (4.1.2) found EA to be lower in the morning for both males and females when participants incorporated mood

testing into their everyday routines; this pattern was replicated in Study 9 (4.4.2) and elaborated in Study 10 (4.4.3), in which women tested in the perimenstruum also experienced a corresponding dip in HT and peak in TA. One explanation for this may lie in the sample. As they were undergraduate students, with lectures tending to start no earlier than 10 a.m., it is not unlikely that they would be used to rising later than many other sectors of the population. As Thayer (2001) states, positive mood and arousal tend to be relatively low upon waking and increase gradually, peaking mid-morning. The time of testing in these present studies might therefore have been too early to encompass this peak.

Although these may not necessarily reflect purely circadian changes rather than entrained rhythms corresponding to established mealtimes and working hours (see Beersma & Gordjin, 2007; also section 1.4.4), the fact that this pattern seems commonplace reinforces the need to consider diurnal changes regardless of their origins. From an applied psychological point of view, the precise physiological mechanisms underlying these apparently diurnal shifts in mood are less of a focus than the actual shifts themselves. As discussed in Studies 9 and 10 (sections 4.4.2.4 and 4.4.3.4), a purely neurobiological study of circadian rhythm effects on mood would require a tightly controlled, constant environment. This, however, would provide little information on variations in everyday mood within a real-life setting. Given that the primary aim of this research is to identify where everyday moods are likely to be less positive so that steps may be taken to maintain a calmer 'baseline' at these points (see Martino & Morris, 2004) it was considered not only appropriate, but necessary to conduct these studies in as naturalistic a context as possible.

Taking into account these limitations, there is some evidence for diurnal variations in mood that correspond to Thayer's 'typical' pattern (e.g. Thayer, 2001). The most interesting observations, however, were not on these diurnal changes *per se*, but on the interaction of the time of day with other factors. The first of note (see Study 1) was that of sex. Whilst males displayed diurnal variations close to the expected pattern, these differed among the female participants. Unlike the menstrual cycle, which is surrounded by expectations and preconceptions relating to social perceptions (see section 1.3), diurnal rhythms are not a gendered phenomenon and do not invoke the same socially mediated biases that may confound menstrual cycle and mood studies.

6.3 Menstrual cycle effects on mood

Although there were clear menstrual cycle-related changes in mood, the study findings contradict the notion of 'Premenstrual Syndrome' (PMS) as being a common occurrence within the healthy female population. When mood was compared across distinct phases of the menstrual cycle (Studies 3 and 4; see section 4.2), within participants' normal, everyday routines, the increased tension associated with the premenstruum and sometimes menstruation itself (see sections 1.3.3 and 1.3.4) was not found. The only effects appeared to be on the 'positive' dimensions of the UMACL, i.e. Energetic Arousal (EA) and Hedonic Tone (HT). Tense Arousal (TA) remained consistent across the menstrual cycle. Although participants tended to feel less energetic during menstruation, this did not correspond to increases in perceived tension. Even where this was accompanied by a reduction in HT, this suggests that mood shifted towards a less positive rather than more negative state.

The UMACL itself may be one reason for why this contradicts numerous findings in the menstrual cycle literature (1.3.4). As discussed in section 1.3.4, the mood scales used in much menstrual cycle research have tended to be negatively oriented. This may not only elicit more negative responses from participants, but also limits the information provided by the scales as they only show alterations in negative states without considering them alongside possible positive changes (e.g. Parlee, 1974). As the UMACL contains both positively and negatively oriented subscales, comparisons can be made between them to contextualise mood shifts. Again, this fits and clarifies Thayer's (e.g. 2001) framework, within which increased tension does not necessarily reflect a negative state (see section 1.2.1). The inclusion of the HT scale to add a third dimension to this framework helps to provide further information on whether changes in subjective energy and tension reflect a positive or negative shift in mood.

Examining all 28 days of the menstrual cycle (Study 5; 4.2.4) revealed that midcycle days were characterised by lower TA as well as higher EA. This, in light of the analyses comparing distinct phases, raises the question of whether menstrual cycle-related changes in mood should be interpreted as a negative shift around menstruation, or a positive shift midcycle. Although the first of the menstrual cycle study series (Study 3; 4.2.2) does indeed suggest a menstrual dip in EA, the other studies in the series appear more in favour of the latter scenario. EA and HT showed a midcycle peak (Study 4; 4.2.4) as opposed to perimenstrual troughs.

Moreover, where there was a negative shift in EA menstrually (Study 3; 4.2.2), premenstrual levels did not differ from those at midcycle. This again contradicts the notion of PMS, and is supported by the finding that cycle-related changes in EA

correspond to changes in HT (Study 4; 4.2.4). HT is linked to feelings of somatic comfort and well-being (see Morris *et al.*, 1998), which are likely to be relatively lower during menstruation; indeed, Cockerill, Wormington & Neville (1994) assert that negative menstrual shifts in mood may be a function of physical symptoms. This seems a more logical explanation for the mood shifts observed in the present research; there is no evidence that women in the premenstrual phase experience negative moods as a result of their 'raging hormones' (see Walker, 1997; also section 1.3).

It is possible that these findings reflect, at least in part, current social trends and views with regards to menstruation and the menstrual cycle. Within a traditional medical model, menstruation and its associated mood changes have been pathologised and labelled as a medical condition or illness (see section 1.3.) and may explain the tendency of menstrual cycle studies to use negatively oriented scales (see section 1.3.4). The lack of support found here for outwardly negative mood shifts around menstruation, coupled with the growing popularity of alternative medicine (see section 1.1.1) implies that women feel more in control of their own moods and health and will 'self-medicate' more readily. Further research utilising qualitative methodology to explore women's experiences of the menstrual cycle in greater depth may shed light on the current findings with regards to their social context.

6.4 Mood and the menstrual-circadian interaction

The research findings support the main hypothesis that the menstrual cycle would interact with the time of day to influence mood, with the most consistent effects occurring on the Energetic Arousal (EA) dimension. In Study 5 (see section 4.2.4), diurnal fluctuations in

EA were phase-dependent among women with natural menstrual cycles, with increased EA in the afternoon occurring in the midcycle phases only. Overall, EA increased in the afternoon, supporting Study 1, which found an afternoon peak in EA in a similar population. Similarly, the higher levels of EA in the midcycle found by studies 3 and 4 (4.2.2 and 4.2.3) were reinforced by Study 5 (4.2.4). Thus the nature of the interaction was to exacerbate these effects so that participants tested in the afternoon experienced a midcycle peak in EA that was not present in those tested at other times of day.

This suggests that although the menstrual cycle may be responsible for some fluctuations in mood, vulnerability to these fluctuations may be altered depending on the time of day. The main limitation of these findings is that cause-and-effect in any particular direction cannot be established. Indeed, Study 9 (see section 4.4.2) found more pronounced diurnal mood fluctuations in women tested perimenstrually, suggesting that vulnerability to diurnal mood changes may be exacerbated by menstrual status. As the results are based entirely on self-report data, they cannot answer the question of whether it is the hormonal changes during the menstrual cycle that affect diurnal rhythms of mood and other variables affecting mood, or these circadian rhythms themselves exacerbating hormonal changes that lead to menstrual cycle-related mood fluctuations. Evidence for the effects of female hormones on sleep patterns (see Manber & Armitage, 1999) and the benefits of sleep deprivation in alleviating PMDD symptoms by 'realigning' circadian temperature and cortisol rhythms with sleep (Parry *et al.*, 2000; 1995) suggests that physiologically, the relationship may indeed be of a two-way nature. A physiological basis for the interaction found here is supported by the lack of such an effect among oral contraceptive users (see 6.4 below).

Nevertheless, the possible role of subjective factors must be acknowledged. Mood is a purely subjective state, so the present research findings cannot be used to assume the hormonal basis for that state. Whilst it is possible that changes in levels of oestrogen and progesterone were at least partly responsible for the mood changes observed, the cyclic shifts in EA may also be directly related to changes in somatic comfort across the menstrual cycle (see Cockerill, Wormington & Neville, 1994). Self-perception of energy and tiredness may not necessarily correspond to physiological states (Rodgers *et al.*, 1995), but may simply reflect affective responses to physical circumstances. Thus, decreased EA around menstruation may well be a psychological response to the physical discomfort associated with it (see 6.2 above).

The specificity of these effects to the afternoon, however, might reflect underlying physiology that is characteristic of the time of day. The afternoon is typically associated with a 'post-lunch dip' (Thayer, 1989; see 6.1 above). Thus, menstrual cycle-related changes in afternoon mood might indicate differential responses to altered blood glucose levels across phases of the cycle. Although Studies 9 (4.4.2) and 10 (4.4.3) yielded similar blood glucose levels during the day when cycle phase was not considered (Study 9) and when participants were tested specifically in the perimenstruum (Study 10), the naturalistic setting of these studies meant that participants were free to self-regulate their own blood glucose levels and were likely to do so according to their own physiological needs (see 6.6 below). Study 12 found that naturally cycling women experienced a reduction in EA after ingesting low-carbohydrate as opposed to full-sugar chocolate, which supports evidence that blood glucose levels are altered by menstrual cycle phase (e.g. Lunt & Brown, 1996; Cawood, Bancroft & Steel, 1993) – specifically,

that the need for glucose is increased during the perimenstruum (Dalton, 1985; Bowen & Grunberg, 1990; Ottley, 2000). Psychological factors may once again have played a part in the results of Study 12, especially given that ingesting more sugar did not lead to increased blood glucose level or improved cognitive performance. Yet the fact that the effect on EA was unique to naturally cycling women does support the notion of at least some physiological basis for these results. The findings fit the observation in Study 5 (4.2.4) that afternoon mood is more vulnerable to these changes, as the second mood test (i.e. that measuring response to chocolate ingestion) took place in the afternoon.

Overall, it appears that diurnal changes in mood are affected by menstrual cycle phase, and that these changes may be partially mediated by underlying blood glucose levels. Afternoon mood seems to be associated with greater menstrual cycle-related fluctuations, which may be a function of phase-dependent responses to food intake among women with natural cycles.

6.5 Oral contraceptives

One interesting observation in the present research was the disproportionately low number of oral contraceptive (OC) users compared with non-users. Of the studies that took this into account but did not compare the groups statistically, only study 3's sample was made up of more OC users (see section 4.2.2.2.1); studies 4 & 10 consisted predominantly of naturally cycling women (4.2.2.3.1 and 4.4.3.2.1).

Where the two groups were compared statistically (Studies 5; 4.2.4 and 12; 4.5.3), effects relating to menstrual cycle phase were unique to naturally cycling women. In Study 5, increased afternoon EA during the midcycle occurred only in those not taking

OCs; OC users, by contrast, showed no cyclical mood variations at all. Similarly, in Study 12 OC users did not experience the drop in EA associated with the consumption of low-carbohydrate rather than full-sugar chocolate as did the naturally cycling women. This suggest that OC users did not have the same need to ameliorate lower blood glucose during the perimenstruum, supporting the notion that OCs abolish the menstrual cycle (Guillebaud, 1984). It also corresponds to reports that oral contraceptives, especially the combined pill, eliminate or at least reduce paramenstrual symptoms, including mood disturbances (e.g. Bancroft & Rennie, 1993; Rouse, 1978; Moos, 1968b, 1969).

Study 12's findings with regards to blood glucose levels do not support evidence for lower blood glucose levels among OC users compared with non-users (e.g. Troisi *et al.*, 2000b; Kjos *et al.*, 1993; Godsland *et al.*, 1990; Perlman *et al.*, 1985); however, the previous studies were carried out on fasting samples, whereas the participants in Study 12 were not required to fast. The lack of a difference in blood glucose levels between the two groups at any point in the study may therefore have been the result of participants having eaten breakfast, which fits in with the idea that individuals will self-regulate their own blood glucose levels throughout the course of the day, as discussed in Studies 9 (4.4.2.4) and 10 (4.4.3.4). There was, however, a difference in perceived palatability of the two types of chocolate between the OC and non-OC groups. Whilst naturally cycling women found the low-carbohydrate chocolate to be equally palatable to the full-sugar milk chocolate, OC users reported a marked preference for the low-carbohydrate chocolate. This could be because they found the full-sugar chocolate too sweet as a result of not needing more sugar. This does not fit evidence for lower blood glucose levels among OC users (e.g. Troisi *et al.*, 2000b), but as mentioned previously those baselines

were obtained for a fasting sample. Moreover, the differences in actual blood glucose levels were slight, and this was unlikely to be sufficient to necessitate increased sugar intake. By contrast it is not unfeasible, given evidence for reduced perimenstrual blood glucose (see Dalton, 1987), that the naturally cycling women in the perimenstruum would have had a greater need for sugar.

The discrepancies in findings across the menstrual cycle study series (4.2) with regards to Hedonic Tone (HT) may be explained by sample differences in the frequency of OC use. Menstrual mood disturbances are associated with reduced somatic comfort (e.g. Cockerill, Wormington & Neville, 1994); studies 4 (4.2.3), 10 (4.4.3) and 11 (4.5.2), which consisted mainly of naturally cycling women, all found the HT scale to be affected by menstrual status. Study 4 found HT to be lower perimenstrually; similarly, baseline levels of HT among perimenstrual women in Study 11 were lower than the baselines of Morris' (2002) sample, in which menstrual cycle phase was not taken into account. HT was also sensitive to diurnal changes among perimenstrual women (Study 10). Study 3 (4.2.2), however, which consisted primarily of OC users, did not yield any cyclical changes in HT. Whilst the menstrual dip in EA among that sample suggests that they experienced some cyclic changes in mood associated with menstruation, and that these changes might have been linked with some level of somatic discomfort, these effects certainly appear less marked than in women with natural menstrual cycles.

Whether the lack of mood fluctuations among OC users is a positive or negative phenomenon is, once more, a matter of perspective. Though OC users did not tend to experience a perimenstrual dip in positive mood in terms of reduced EA and/or lower HT, the obverse is that they did not experience a midcycle peak. This, and the fact that it

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tended to be the positive rather than negatively-oriented UMACL subscales that were affected by the menstrual cycle (4.2; see also 6.2 above), means that eliminating the mood fluctuations associated with the menstrual cycle may not necessarily be advantageous among a healthy population.

6.6 Blood glucose levels, cognitive demand and mood

The third experimental study subset (see Section 4.3) demonstrates clear support for established findings of enhanced mood with maintaining or increasing blood glucose, with some evidence for improved cognitive performance. The importance of cognitive demand in regulating mood responses to blood glucose changes is also highlighted.

The results of Study 6 (4.3.2), which simply indicated improved mood at the start of the working day with the consumption of a glucose-rich drink, supported previous findings of increased energy and reduced tension with elevated blood glucose (e.g. Gold *et al.*, 1995; Benton & Owens, 1993). These findings were also extended by the use of the Hedonic Tone (HT) scale to show that raising blood glucose also enhanced the overall pleasantness of mood.

When cognitive performance was brought in, however, the findings became considerably less straightforward in relation to the literature. Contrary to numerous reports of improved cognitive performance resulting from the ingestion of glucose (e.g. Morris & Sarll, 2001; Benton & Sargent, 1992; Lapp, 1981), Study 7 (4.3.3) found no direct relationship between glucose ingestion and improved performance, with improved performance on the second attempt at a recall task among both participants imbibing a glucose-rich drink and a control group consuming a saccharine-based placebo. One

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interpretation of this effect is that it reflected improved recall as a result of practice. The alternative, however, is that those consuming the saccharine drink had maintained a level of performance comparable to those who had taken glucose. Indeed, the glucose group reported lower Tense Arousal (TA) and less interference, as well as higher concentration and more pleasant mood (as measured by the HT scale), indicating that the glucose was sufficient to have psychological benefits. This, combined with the maintenance of performance in the saccharine group, is possibly a manifestation of the compensatory strategy proposed by Hockey (1993; 1997), which would suggest that the effects on the saccharine group represented the affective costs of increased mental effort investment resulting from reduced glucose availability (see Fairclough *et al.*, 2004). Support for the 'performance maintenance' hypothesis comes from Study 8 (4.3.4), which indicated a facilitating effect of glucose on performance of the Stroop task by reducing the number of errors made.

A further finding of note from Study 8 was the moderating effect of trait anxiety on both performance of the Stroop task and on mood response to the task. Initial analysis irrespective of trait anxiety revealed no effects of glucose on mood, contradicting the previous studies in the series as well as the literature (see section 1.2.3); however, partialling out the effects of trait anxiety not only removed the positive effects of glucose on performance, but also revealed reduced tension among the participants drinking glucose who were tested in the morning. The relationship between blood glucose and the time of day is elaborated below (6.6). In terms of anxiety, cognitive performance and mood, the findings suggest that the way in which an individual utilises glucose in cognitive functioning is somehow dependent on their level of trait anxiety. Similarly,

how anxious they are in general also impacts upon the way in which they respond to such tasks.

As a whole, this study subset demonstrates the importance of blood glucose levels in both mood and cognition, which in itself has useful implications for maintaining positive mood throughout the working day. However, the role of trait anxiety is particularly salient in the prevention of workplace stress. If some individuals are more vulnerable than others to the effects of certain stressors, then the efficacy of interventions for reducing these effects will depend to some extent on these individual differences.

6.7 Blood glucose and biological rhythms

Evidence for a diurnal blood glucose rhythm (Troisi, Cowie & Harris, 2000a; Bolli & Gerich, 1984; Bolli *et al.*, 1984) was supported by Study 8 (4.3.4), which demonstrated higher blood glucose levels among participants tested in the morning as well as a greater increase in blood glucose following glucose ingestion compared with those tested in the afternoon. Testing blood glucose levels throughout the day, however, revealed no circadian patterns (Studies 9; 4.4.2 and 10; 4.4.3).

The absence of circadian blood glucose patterns when measured throughout the day is likely to be a function of the methodology. These studies were designed to be as naturalistic as possible to capture fluctuations in blood sugar levels and mood during the course of a participant's normal day. Participants were not in any way restricted in terms of what they could eat and when; consequently, they were able to maintain their blood glucose levels via food intake. As discussed in section 1.4.4, the ready availability of food and the effects of entrained mealtimes make it difficult to examine genuine

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circadian fluctuations in blood glucose levels without using a starving sample. Pure research into circadian rhythms requires a rigorously controlled, constant environment; as pointed out above in relation to circadian rhythm effects on mood (6.1), this would in itself have an impact upon mood state and would thus defeat the object of the research. In addition, the study sample consisted of young, healthy individuals, who would therefore have had good glycaemic control (see section 1.2.2). Any fluctuations in blood glucose would be regulated quite quickly, so might not become apparent even with hourly testing.

However, as with the findings on diurnal mood fluctuations, this does not mean to say that these results do not have practical or applied significance. One might argue that among a healthy population with ready access to food and good glucose tolerance, there is no real cause for blood glucose levels to show marked fluctuations. Moreover, the fact that individuals appear to self-regulate their blood sugar levels over the course of a typical day has useful implications when considering the possible role of blood sugar levels in maintaining well-being.

The effects on mood over the 12-hour study period were interesting nonetheless. Study 9 (4.4.2) showed that Energetic Arousal (EA) was lower in the morning than at other times, and that despite the absence of diurnal changes in blood glucose level, higher blood glucose was associated with greater EA and HT. There are two interrelated explanations for this observation. One possibility is that lower EA in the morning represented the affective cost of keeping blood sugar levels constant either in the absence of food intake, the requirement of mental effort, or both (see section 1.2.3). Many of the study sample were students who would have been attending morning lectures at the time, so this is not unlikely. An alternative, and indeed related explanation is that participants'

food intake during the day was a response to their mood states, so that changes in underlying blood glucose levels would not have been apparent even with the observed shifts in EA. Again this does not seem unlikely, given the observed correlations between blood glucose and mood.

The relationship between blood glucose and the menstrual cycle also yielded mixed results. Although the effects on mood observed in Study 9 (4.4.2) remained present and were even enhanced among women in the perimenstruum (Study 10; 4.4.3), reinforcing the nature of the menstrual-circadian interaction as diurnal mood rhythms being enhanced rather than altered by menstrual cycle phase (see 6.3 above), no relationship was found between blood glucose and mood for this group. Whilst it is possible that these mood fluctuations were simply unrelated to any changes in blood glucose levels, another explanation may lie in food consumption and preference during the perimenstruum. Study 12 (4.5.3) found that perimenstrual women with natural menstrual cycles experienced a reduction in EA following the consumption of low-carbohydrate chocolate compared with a full sugar equivalent. This supports evidence for menstrual cycle-related changes in blood glucose (Lunt & Brown, 1996; Cawood, Bancroft & Steel, 1993; Walsh & Malins, 1977; Cramer, 1942) by suggesting that these women had a greater need for glucose; this view is reinforced by the lack of such an effect among oral contraceptive users also tested in the perimenstruum (see 6.5 above). Consequently, evidence for changes in food preference across the menstrual cycle (see section 1.3.6) may represent a physiological basis for cravings (Rogers & Jas, 1994; Bowen & Grunberg, 1990) rather than a psychological desire to improve mood through the consumption of pleasant-tasting food (Hill & Heaton-Brown, 1994). Even though

some authors have suggested that perimenstrual food cravings are driven by appetite rather than specific nutritional needs (Vlitos & Davies, 1996; Barr *et al.*, 1995), the findings of Study 12 alongside consistent menstrual cycle-related changes in Energetic Arousal throughout the present research may indicate a need to increase overall energy intake perimenstrually.

6.8 Interventions for maintaining positive mood and well-being

As stated from the outset, one of the primary aims of the present research was to suggest effective but manageable interventions for maintaining a positive mood state and psychological well-being. Two different types of intervention were tested within very different settings that were nonetheless representative of contexts that would be relevant to the majority of the target population. Furthermore, women were specifically targeted during the perimenstruum, where less positive shifts in mood are more likely to occur (see section 4.2)

Martino & Morris (2004) highlight the convenience of such a simple intervention, asserting that substituting one's daily shower with just a 10-minute bath provides 'downtime' any people often neglect to take. This intervention was recommended for the start of the working day to set a calmer baseline upon arriving at work; given that the present research found mood to be less positive in the morning, particularly around menstruation (see section 4.2), this may well be a useful strategy for maintaining a positive perimenstrual mood state particularly for women who feel that they are more vulnerable to mood shifts during that time. Being able to easily fit such an intervention into one's everyday routine is especially relevant to those women

experiencing stress as a result of 'role conflict' (see section 1.1.2). As Morris and Wickes (2007) acknowledge, although there are many non-drug therapies available for enhancing psychological being, such as exercise, meditation and massage, there are often practical reasons which prevent people from taking them up. Meditation, for example, takes considerable skill to successfully master, and massage can prove expensive. Moreover, these methods require time that many feel they do not have or are not ready to commit to, particularly those already under pressure. Using bathing as a technique for enhancing mood, with or without the addition of aromatherapy oils, can help provide valuable downtime to individuals who would otherwise struggle to accommodate breaks in busy schedules.

The second intervention, chocolate, has received much attention on a popular basis with regards to mood and health, particularly in relation to the menstrual cycle. However, whilst much of the focus has been on its psychoactive ingredients and their apparently magical properties for mood-enhancement, its sugar content and effect on blood glucose levels is perhaps a more logical, albeit simpler explanation. Study 12 actually found no effects of either conventional full-sugar chocolate or a low-carbohydrate version on blood glucose levels in perimenstrual women. This was likely to be a reflection of good glucose tolerance among the sample (see section 1.2.2), as well as the lower glycaemic index (G.I.) of the chocolate compared with the glucose drinks used in earlier studies. Memory for information presented via video was also unaffected.

There were, however, marked effects on mood. Tense Arousal was lower following both types of chocolate, an effect that was still present 90 minutes after consumption. This suggests that in a situation requiring cognitive effort, a snack may

help to offset the affective costs of utilising more glucose (Fairclough *et al.*, 2004). From this point of view, the chocolate helped maintain blood glucose levels even though it did not elevate them. Similarly, the lack of improvement in memory recall could be interpreted as maintenance of performance by maintenance of blood glucose levels. This would not be unreasonable considering that the second test took place at around 12 p.m., by which time blood glucose levels would have started to fall and participants would have been relying on the mobilisation of glycogen from the liver to maintain optimal concentrations. There is evidence to suggest that maintaining blood glucose in this way does not have the same psychological and cognitive benefits as a more direct supply via food intake. For example, in a study of similar design Morris & Sarll (2001) found improved listening span in students consuming glucose but not those consuming saccharine, despite no changes in blood glucose levels. This suggests that the chocolate used in the present study was sufficient in both cases to maintain blood glucose to a level where mood was enhanced and cognitive performance not impaired.

The glucose maintenance hypothesis is supported by the effects of oral contraceptive use on Energetic Arousal (EA). There was a selective decrease in EA following the low-carbohydrate chocolate, in naturally cycling women only. Given the evidence for menstrual cycle-related changes in glycaemic control (see section 1.2.5), as well as the absence of mood effects in oral contraceptive users (see 6.4 above), it appears that while blood glucose levels and cognitive performance were maintained among these women, there were nonetheless subtle affective costs. This suggests that foods with a slightly higher G.I. may be more appropriate for maintaining feelings of energy around menstruation.

Overall these findings have useful implications for enhancing and maintaining positive mood at home and in the workplace. They are both efficacious, yet simple and convenient enough to incorporate into one's everyday routine at a low cost. Most importantly, they do not have the detrimental effects on health of many commonly used forms of self-medication, such as cigarettes and alcohol. Whilst the excessive consumption of chocolate is not recommended, it is certainly a preferable option to spiking one's blood glucose with sugar-laden drinks. For the very health-conscious it could even be substituted with healthier foods of a similarly moderate G.I., such as nuts or dried fruit.

7. CONCLUSIONS

The present research has demonstrated both diurnal and menstrual fluctuations in mood, as well as an interaction between the two. Diurnal variations in mood are exacerbated rather than altered by menstrual status, with naturally cycling women in the premenstrual to menstrual phases more vulnerable to shifts in mood. Contrary to pervasive stereotypes, however, these shifts are not necessarily of a negative nature and are often subtle. Considering the different dimensions of mood shows that contrary to being more 'negative' at certain points, mood can be less 'positive'; for example, a mood state may be 'anchored' by conservation of Tense Arousal and Hedonic Tone, with Energetic Arousal adapting to physiological and environmental states. Furthermore, there is an element of subjectivity in the interpretation of whether a shift in mood is positive or negative; a pattern that shows a menstrual dip may also have a midcycle peak. Similarly, oral contraceptive users do not tend to experience these fluctuations; whether this is viewed as good because it eliminates these menstrual dips, or bad because it also eliminates the midcycle peaks is again subject to interpretation. Either way, the concept of women being victims of their 'raging hormones' is by no means upheld by the present findings.

Blood glucose levels appear to have an underlying role in the relationship between these biological rhythms and their effects on mood. Maintaining stable, moderate levels of blood glucose has beneficial effects on both mood and cognition, and responses to cognitively demanding situations. Where this is compromised, consuming a convenient form of glucose may help ameliorate the effects of falling blood glucose

levels. A snack that is lower in simple carbohydrates can be just as effective in doing this; however, women who are not taking oral contraceptives may have a greater need for glucose during the weeks before and during menstruation.

With regards to cognitive performance and demanding situations, both the menstrual cycle, the time of day and blood glucose levels can influence the way in which an individual responds to and copes with such situations. When applied to the real-life scenarios of work and study, it is clear that these factors play a part in maintaining psychological well-being and avoiding the negative effects of potential stressors. Furthermore, levels of trait anxiety appear to modify responses to these stressors. Evidently, mood states among healthy women are influenced by a complex interplay between biological rhythms, physiological states, individual differences and the context in which these moods take place. Nevertheless, whilst individual circumstances will inevitably be a major determining factor in the time one can invest in reducing stress and enhancing well-being, simple interventions that can easily be incorporated into even the busiest schedule can be efficacious in maintaining a calm-energetic baseline.

Based on the findings of these research studies, considered in the context of biopsychosocial models of health and well-being, it is thus recommended that:

1) Women are aware of times where mood may be less positive, or where they may be susceptible to more negative shifts in mood, so that steps may be taken to maintain positive states or ameliorate negative changes;

2) Substituting one's daily shower for a 10-minute bath, with or without the addition of aromatherapy oils, may help set a clam-energetic 'baseline' for beginning the working day;

3) Conscious efforts are made to keep blood glucose levels stable at a moderate level (approximately 5-7 mmol/l) to maintain an optimal balance of mood and cognitive functioning, and to facilitate coping with demanding tasks and situations;

4) Where blood glucose levels are lower than optimal, individuals can 'self-medicate' in the immediate or short term by consuming convenient forms of glucose;

5) However, due to the potential long-term implications for health, self-medicating with high-sugar foods is not recommended on a regular basis. Consuming regular meals and snacks consisting of slower-release forms of energy will keep blood glucose at ideal levels for maintaining positive mood and cognitive functioning, without compromising physical well-being.

It is vital to emphasise that the subjective nature of mood and stress is not a problem in research of this kind, but a fundamental principle. As concluded by Walker (1997), the question of whether PMS or related phenomena actually exist should not really be the question. In terms of women's health, what matters is that women's accounts of their experiences are taken seriously and acted upon as necessary, even though conceptualising perimenstrual mood fluctuations as problematic may not always be appropriate. Accordingly, the idea that the very concept of stress as explains 'everything and nothing'

(Cassidy, 2001) does not lessen its impact or devalue the experiences of those who encounter it. Instead of pathologising mood responses to physiological and environmental circumstances and trying to find a 'cure', it is perhaps more useful to acknowledge why these responses occur and take positive steps to prevent them from progressing into a problematic or dysfunctional state.

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