

**BEHAVIOURAL EFFECTS OF CAFFEINE:
THE SPECIFICITY HYPOTHESIS**

A thesis submitted for the degree of Doctor of Philosophy

By

WENDY SNOWDEN

School of Human Sciences and Law,
Faculty of Society and Health,
Buckinghamshire New University

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Abstract

This thesis argues that caffeine use offered a survival advantage to our ancestors and that moderate use continues to offer modern humans benefits. Caffeine ingestion, through the blocking of adenosine receptors, elicits broad elements of the mammalian threat response, specifically from the ‘flight or fight’ and ‘tend and befriend’ repertoires of behaviour: in effect, caffeine hijacks elements of the stress response. If the effects of caffeine had been discovered recently, rather than being available to *Homo sapiens* since Neolithic hunter gatherer times, it is likely that caffeine would be considered a ‘smart’ drug. More caffeine is being ingested today than ever previously recorded. Caffeine use is found across all age groups, all socio-economic strata, most ethnic groups, and is being used increasingly by the medical and pharmaceutical industries and by the armed forces. Yet despite this wide usage and a substantial body of research literature, there is at present no clear pattern or plausible model for the way caffeine achieves its effects. There is much contradiction in the literature and ambiguity as to why caffeine use should improve performance on some tasks, impair it on others and have no effect on other tasks, for some but not all of the time. The present work argues, through an examination of the specificity of caffeine’s operation, that these effects are not arbitrary but elicited by the nature of the tasks, in particular that caffeine ingestion affects those processes and behaviours which improve the probability of survival under perceived threat or stress. This is argued through the perspective of evolutionary psychology and relies theoretically on Polyvagal Theory. The argument generates testable hypotheses and empirical support for the thesis is garnered from nine experiments on card-sorting, verbal and numerical processing, local and global categorization, field dependence-independence, the Stroop task, tests of visuo-spatial ability, and from a correlational study of caffeine use and personality traits. It is concluded that moderate caffeine use in healthy adults promotes behaviours likely to be adaptive under perceived threat or stress. Limitations of both theory and empirical work and are discussed, together with potential practical applications and suggestions for further work.

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This thesis is dedicated to Emma for her sharp eyes, even sharper intellect and unfailing good humour.

Author's Declaration

I confirm that this is my own work and the use of all materials from other sources has been properly and fully acknowledged.

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Chapter One

Framing the Research Question: Moderate Caffeine Use in Adults Elicits Specific Processes at Physiological, Cognitive and Social Levels, Processes which Transmute into Adaptive Behaviours.

1.1. Overview

Caffeine's effects, whilst disparate, are also specific. Caffeine ingestion has been shown to enhance certain perceptual and cognitive processes, which have the effect of improving vigilance performance, whilst not affecting other apparently similar cognitive and perceptual processes. As well as improving vigilance, caffeine ingestion extends stamina and enables wakefulness in situations which create extreme fatigue. It has also been reliably shown that caffeine use improves 'distance' sports, though not 'power' sports, that is caffeine increases the potential to escape dangerous situations (exit velocity and endurance), without the exposure to harm which accompanies fighting. Caffeine use markedly improves pain relief when in the presence of either synthetic or endogenous painkillers. In addition, negative correlations of caffeine use with cardiovascular disease (CVD), diabetes, liver disease, asthma and Alzheimer's disease have been reliably reported in humans, together with the capacity of caffeine use both to prevent and reverse the mouse equivalent of Alzheimer's disease in knockout mice. Lastly, drinks which contain caffeine such as coffee, tea, chocolate and colas are seen and widely used to promote sociability.

In view of the above effects and the increasing use of caffeine by both the general public and the medical professions, a better understanding of how and why caffeine effects are achieved is desirable. The present thesis argues, from an evolutionary psychology perspective, that the behaviours promoted by caffeine use are adaptive. Valuable as the evolutionary perspective is, it is acknowledged that a major disadvantage is that some arguments, together with supporting evidence, may be considered *post hoc*. For example, it might be argued that the beneficial effect of caffeine use on diseases which affect the elderly who are long past the age of reproduction, is unlikely to be adaptive. However, if one considers the better outcomes for children which are associated with having contact with older family members, the 'grandmother effect', then the claim is less unreasonable, whilst it clearly remains *post hoc*. However, there are other elements of the thesis, such as the effects of caffeine use

on some but not other perceptual and cognitive process and the increasingly greater use of caffeine, which are more readily testable and falsifiable, which are explored in detail in this thesis.

Despite sustained and substantial attention by researchers there is presently no available model of caffeine's overall behavioural effects, notwithstanding worldwide ingestion of caffeine through the vehicles of, *inter alia*, coffee, tea and cola drinks. Within the research data there are many conflicting and ambiguous findings, together with a number of paradoxes, such as the finding that caffeine appears to improve performance on some aspects of cognition, whilst failing to do so in related or similar areas and to have both beneficial and deleterious effects on health. This thesis offers a model of the behavioural effects of caffeine use which, arguably, is able to account for these apparent paradoxes, together with all presently known reliably documented effects of caffeine. It is argued that moderate caffeine use in healthy adults elicits better performance on a specific range of perceptual, cognitive, physical and social activities.

In essence, the argument is about specificity and is twofold. Firstly, that the increased arousal brought about by caffeine ingestion elicits benign bodily resources which engage a wide range of currently known behaviours constituting the mammalian response to perceived threat (or 'stress'), whereas no other substance that is consumed voluntarily on a day to day basis does. That is, the ability to elicit mammalian response behaviours and stress resources is **specific** to caffeine. Other stressors ingested on a daily basis, such as alcohol or fluoride, have very different and far more damaging effects from the ingestion of caffeine, without any apparent benefits. Secondly, all the behaviours reliably documented under caffeine ingestion are also seen in mammals when under stress (apart from enhanced social engagement, which is seen only in certain apes). That is, caffeine does not elicit any behaviours which are not part of the mammalian stress response. Hence caffeine's behavioural effects are **specific** to the mammalian stress response. It is argued that these two effects demonstrate that caffeine use in moderation is both specific and promotes adaptive behaviours in situations of perceived stress.

Caffeine's ability to create a state of increased arousal is central to the argument. Although neither psychologists nor neuroscientists regard arousal as a single unitary

process (Robins and Everitt, 1995) there is general agreement that increases are incremental and graduated. As arousal increases, behaviour changes in line with these increases until a point is reached where action and diffusion are inevitable, for example, if the increased arousal is due to perceived threat, through flight or fight behaviour. Individuals, human or animal, who have ingested caffeine are further along the arousal continuum (threat perception, conscious or unconscious, plus caffeine arousal) than those who have not and are therefore in a position to respond to the threat earlier than non caffeine drinkers. Although research shows that this difference is often only a matter of seconds, or milliseconds, in a situation of threat this small difference may be sufficient to alter outcomes. With regard to a number of perceptual, cognitive, physical and social responses, all with the potential to enhance survival in a threat situation, caffeine ingestion promotes a winning edge.

The thesis argues, within the perspective of evolutionary psychology, that caffeine, through the blocking of adenosine receptors and the consequent increase in physiological arousal, elicits specific mammalian behavioural survival strategies from a phylogenetically ancient stress-arousal survival system, releasing additional bodily resources with which to combat or escape perceived threat. Hence those mental processes and aspects of behaviour which increase the probability of surviving a dangerous situation will show effects of caffeine ingestion, whereas other apparently similar processes and behaviours will not: that is, the effects of caffeine use are specific rather than generalised. The experimental work in this thesis is mainly concerned with such behaviour, but it is perhaps worth noting that in addition to the direct, fast acting, effects of caffeine, the breakdown products, theophylline and theobromine, which are released more slowly, have strong antioxidant and antitussive properties which are implicated in the protective effects of caffeine ingestion against diabetes, liver disease, asthma and cardiovascular disease.

When caffeine has not been ingested, perception of potential threat increases arousal: consequently, when caffeine has been ingested, the subsequent increased arousal is interpreted as due to potential threat (in the absence of alternative competing 'increased arousal' hypotheses, such as sexual opportunity). Hence, elements of behaviour from the ancient freeze, fight or flight syndrome, together with stress diffusion behaviours in primates, are activated by moderate caffeine use.

Polyvagal Theory, described originally by Porges in 2001 and in continuous further development to date, offers a psychophysiological explanation of the mechanisms through which perceived changes in the level of threat in the internal or external environment are transmuted into behavioural change. In effect, the drug caffeine acts as a mild but powerful stressor, creating the perception of an increased level of threat which, through a cascade of physiological changes orchestrated by the Autonomic Nervous System (ANS) and Social Nervous System (SNS), precipitates a higher level of neuronal readiness for action, consequently enhancing defensive behaviours. These stress-induced physiological changes, induced either by caffeine or by potential threat in the environment, elicit faster response times together with broader cognitive changes, for example, faster orienting, faster categorisation, shifts in attentional focus, shifts from global to local processing and shifts in motivational focus, such that perceived threat is monitored and responded to more effectively.

It is being argued that caffeine use promotes survival orientated behaviours, in the sense that it increases sensitivity to perceived internal and external threat. This notion, which is confirmed by the experimental work reported later, was originally derived from the remarkable concordance of the behavioural effects of caffeine use and the behavioural effects of stressors, as reported in the psychological and medical literature, both caffeine and perceived stressors eliciting strategies which may be considered survival orientated. The concordance is reviewed in Chapter Two.

Although the literature of the effects of caffeine ingestion has burgeoned over the last fifty years or so, the focus of research has varied throughout that time. For example, early research examined the effects of caffeine ingestion on discrete behaviours, such as vigilance, performance on the Bakan Rapid Information Processing task or endurance skiing, whereas much of the more recent research in the area has focussed on the effect of caffeine ingestion on living brain function, measured electronically. This change of focus means that in many instances it is not possible to compare past findings of discrete behaviours with recent findings of brain function because early brain function studies appear not to exist. However, it is hoped that the focus on brain studies will bear fruit eventually.

The degree to which caffeine ‘hijacks’ elements of the stress response, rather than merely eliciting it, is a moot point which may not be answerable until the stress response itself is more fully understood. However, moderate caffeine use in healthy adults may be seen as promoting adaptive behaviour, since it elicits, specifically, threat-monitoring and survival strategies.

In order to support the argument that caffeine elicits phylogenetically ancient behaviours, which developed in response to perceived threat, an evolutionary model of stress-arousal is put forward for consideration. It will be argued that caffeine use elicits several (though not all) behaviours from the repertoire of strategies integral to the evolutionary model of stress-arousal: for example, caffeine use facilitates flight but not fight behaviours, whereas alcohol does the reverse. It is acknowledged that the argument that caffeine use hijacks elements of the stress response is somewhat radical, so it is assessed from two perspectives, both through an evaluation of the ability of the new explanatory framework to account for past research findings, many of which have previously been considered contradictory, and through an evaluation of the new model’s predictive power. Data from nine experiments on caffeine’s effects on behaviour, together with two correlational studies, are used to this end.

1.1.1. Rationale for the Thesis

In essence, the research question is ‘what are the effects of caffeine on behaviour and through which mechanisms are these effects achieved?’ It is argued that a comprehensive model and theoretical framework for the effects of caffeine is long overdue. In the present thesis the behaviours examined are largely perceptual-cognitive, since it was not practical to examine speed of flight and endurance in the face of serious threat to well-being. Apart from inherent interest in the issue, there are cogent, pragmatic reasons why such a model is necessary. Caffeine use, which is already endemic, continues to increase through the voluntary consumption of known caffeine-containing foods, particularly beverages, especially amongst children. In addition, caffeine is widely used in pain management as a constituent of both over the counter (OTC) and prescription drugs. Caffeine is also being used increasingly in slow release form (SRC), both to counteract jet lag and, amongst specific groups, such as the armed forces, to counteract the sleep deprivation that active service or practice manoeuvres

often entails. Caffeine is also currently being evaluated by the medical profession as a possible drug regimen compliance mechanism.

In relation to the latter application, it may be unwise to administer caffeine regularly, as in the last two examples of use, without a fuller understanding of the drug's effects and the mechanisms through which these are achieved. Lastly, in addition to other effects generally considered beneficial, caffeine use has a number of known negative effects, such as the adverse effects on reproduction in both males and females. Although moderate caffeine use in adults appears to be very safe (apart from effects on fertility and fecundity), excessive use may be fatal: Kerrigan and Lindsey (2005) report two examples of individuals, one a 39 year old woman, the other a 29 year old man, who suffered fatal caffeine overdoses. Hence it is argued that a substance in common and increasing use, with documented negative effects, merits further investigation aimed at clarifying its precise mechanism of action. All these issues are discussed in greater detail below.

1.1.2. The Caffeine Paradoxes

When the literature on the behavioural effects of caffeine is explored, many paradoxes become apparent: six such paradoxes are considered briefly below and in more detail throughout the thesis.

1.1.2.1. Paradox One: Drug Use Without a Perceived 'Benefit'

There is evidence that caffeine has been used by humans since Neolithic times (Escohotado 1999), is found in at least sixty different plants, that it is used all over the world and that it is the most widely used self-administered drug known. Where surveys have been made, a figure of over 95% of adults using caffeine is normative (excludes Muslim countries). Despite this wide usage, there is no generally acknowledged benefit of caffeine use. This is very different from the use of aspirin, ibuprofen and other self-administered drugs which offer pain reduction benefits, 'dance' drugs which allow the user to dance energetically for many hours longer than they would otherwise be able and 'leisure' drugs which create an obviously altered state of consciousness in the user.

The notion that caffeine improves mood is not generally supported by research evidence, though some researchers, for example Haskell, Kennedy, Wesnes and Scholey

(2005) have found that it does: in many cases the opposite is true. The idea that caffeine increases general alertness, equally, is not supported by research evidence: caffeine improves performance on a very narrow range of behaviours under very specific circumstances, whilst impairing performance on other behaviours. A resolution to the paradox of the historical, and presently almost ubiquitous use of caffeine with no obvious payoff, would be to find evidence for a benefit, as yet unidentified in the research literature, from caffeine use. It is argued here that caffeine's ability to prime survival orientated behaviours is such a benefit.

1.1.2.2. Paradox Two: Effects of Caffeine Use on the Health of Physical Systems

Caffeine use is known to exacerbate a number of risk factors associated with cardiovascular disease (CVD), for example, caffeine ingestion results in increased heart rate, increased blood pressure and increased cholesterol levels, (Bichler, Swensom and Harris 2006) yet, despite initial assumptions of deleterious effects on CVD, carefully controlled studies show no ill effects of moderate caffeine use (James 1997). Similarly, caffeine stimulates the insulin response, leading to the reasonable expectation that caffeine use would be positively correlated with diabetes, whereas in fact caffeine use is negatively correlated with levels of diabetes (Van Dam 2006). However, the effect of caffeine use on health is not always positive, since fecundity and fertility in both males and females is reduced by even very moderate caffeine use (Christian and Brent 2001). Hence the effects of regular caffeine use on physical health are not general but specific to particular bodily systems, sometimes being beneficial, sometimes deleterious and sometimes having a neutral effect. It will be argued that this pattern of effects is derived from a combination of the body's response to threat and the antioxidant effects of the breakdown of caffeine. Caffeine's negative effect on reproduction may be seen as contradictory to the notion that caffeine use is generally beneficial: whilst reducing reproductive success for the individual may be seen as damaging, in the wild it is commonplace for stress to inhibit breeding. Conservationists argue that successful breeding in a stressful environment, were it possible, would be likely to weaken the breeding group as a whole, and hence be maladaptive.

1.1.2.3. Paradox Three: The Effect of Caffeine Use on Sports Performance

The effect of caffeine on sports performance is well documented but at present there is a lack of explanation as to why some, but not all, kinds of sport benefit from caffeine

ingestion. For example, although the mechanism of caffeine's ergogenic effects, through the enhanced release of calcium into muscle cells, is well understood (Keisler and Armsy 2006), there is at present no explanation as to why these effects should be found in 'distance' sports, such as running and skiing, but not in 'power' sports, such as weight lifting. These differential effects are predictable when caffeine use is conceptualised as eliciting adaptive behaviour to a potentially threatening environment. Being able to lift heavy weights is unlikely to improve survival rates, whereas being able to outrun a threatening individual, human or animal, may well do so.

1.1.2.4. Paradox Four: The Effect of Caffeine on Behaviours Associated with Different Personality Types

Established theories of personality contain a factor, usually called extraversion, describing the tendency towards being impulsive, active, aggressive, sociable and talkative, together with other factors such as neuroticism, openness, conscientiousness and agreeableness. Caffeine use is positively associated with some extravert behaviours, such as being active and talkative (Jones and Lejuez 2005) though not with others, such as being aggressive and changeable. On the other hand, caffeine use is positively associated with neurotic behaviours, such as increased anxiety and wariness that is, caffeine use appears to affect personality types, and traits within those personality types, differentially. In addition, caffeine use is negatively correlated with a tendency towards depression (Alsense, Deckert, Sand and de Wit 2003). Arguably, the best and most coherent explanation for this pattern of effects is that caffeine use increases arousal and elicits specific survival orientated and threat related behaviours, such as an increase in activity, vocalisation, anxiety and wariness: behaviours which, in personality theory, are associated with different personality types.

1.1.2.5. Paradox Five: Ambiguity of Findings on Caffeine's Effects on Perception and Cognitive Performance

The beneficial effects of caffeine use on some (but not other) aspects of cognitive performance have been recorded in the research literature over many years, without the emergence of a compelling rationale for the pattern of effects. Van der Stelt and Snel (1998) comment, in a comprehensive review, that 'The results from different studies were often at variance with each other' (p. 179), whilst Lorist (1998) argues that it is difficult to find a consensus on caffeine's effects, even at a descriptive level, and James

(1997) concludes from his biobehavioural analysis that caffeine's effects are sometimes ambiguous and far from clear cut. The present thesis offers a plausible rationale and explanation for much of this historical ambiguity.

1.1.2.6. Paradox Six: Lack of a Model of Caffeine's Effects

Despite the substantial body of research findings on caffeine and evidence of caffeine's effects on disparate aspects of behaviour, a satisfactory model of caffeine's effects has yet to be developed. At present (2009) there are approximately 34,000 peer reviewed papers on the effects of caffeine (Pubmed 2009). Despite the interest and scholarship which these papers represent, there is as yet no overall model of caffeine's behavioural effects, although Lorist (1995) has developed a model of caffeine's effects on human information processing only, which appears to be the closest attempt, so far, at such an endeavour. This model focuses primarily on caffeine's effects on 'input' and 'output' processes. The model displays much merit but is not able to account for the disparate pattern of effects of caffeine on aspects of cognition reported in prior research, nor to offer a rationale for why caffeine should affect input/output processes under some 'energetic' states but not under others. In addition, Lorist's model attempts to account for caffeine's effects on cognition only, whereas a compelling model would be able to offer a plausible rationale for the wide spectrum of caffeine's effects on other aspects of cognition and behaviour as, it is argued, does the model put forward here.

Part of the reason for past contradictions in the caffeine literature may be the failure of some early researchers to distinguish between the effects of ingesting caffeine *per se* in tea, coffee, chocolate and cola and the effects of substances such as theophylline and theobromine, which result from the breakdown of these beverages by the body. During digestion tea and coffee release theophylline, a powerful antioxidant, whilst chocolate releases theobromine and cola releases appreciable amounts of neither. Decaffeinated coffee also contains theophylline. However, the effects of caffeine are measurable within minutes, whereas the body takes longer to process theophylline and theobromine. For the purposes of this project, the terms 'coffee' and 'cola' indicate that both substances contain caffeine, unless specifically designated as 'decaffeinated'.

Each of the six paradoxes enumerated above is considered in more detail throughout the development of the present thesis. It will be argued that when caffeine's effects are

considered within the framework of an evolutionary model of stress-arousal all the above paradoxes are resolved.

An important element of constructing a reliably predictive model of caffeine's behavioural effects is to identify which factors distinguish between events which elicit behavioural change under caffeine ingestion and which do not. The current approach to this enigma in the literature is to describe some types of tasks as 'sensitive' to caffeine, whilst other tasks are 'insensitive' and still others are sensitive to caffeine in some circumstances but not others. Van der Stelt and Snel (1998) summarize this position as follows: 'the influence of caffeine on performance is selective, in that some features of performance are more sensitive than others, complex, perhaps representing patterns of behavioural facilitation and interference and not constant, in that it can be moderated by a wide variety of variables' (p. 180). Though this approach is useful for the purposes of description and review, inevitably it is unable to offer predictive premises amenable to testing and to practical application. However, it is argued that if the notion of tasks being 'sensitive or insensitive to caffeine' were to be replaced by the notion of 'tasks with the potential to improve the chances of survival when under threat,' hypotheses amenable to testing and offering the opportunity of practical application will readily emerge.

1.2. The Thesis

The thesis being presented here is that the specific changes in behaviour elicited through caffeine ingestion give the caffeine user an increased probability of survival in certain circumstances. Clearly caffeine use is unlikely to protect an individual from involvement in a train or plane crash, but it may reduce his chances of being involved in a car crash, and of escaping from a hostile animal or human. Caffeine use primes threat monitoring processes and this, together with the triggering of the well documented bodily changes which accompany a sense of threat, promote a greater probability of survival or fitness. 'Fitness' is being used here in the classic evolutionary sense of increasing the survival chances of the individual and/or the individual's genes, in the face of conditions which are either threatening or perceived as threatening. The thesis that moderate caffeine use promotes adaptive behaviour may be considered counterintuitive and thus it is explored through extant and novel theory and evaluated

against extant and novel research findings. In order to do this, the following steps are taken, with necessary terms being defined at each stage of the argument:

- The theoretical perspective of evolutionary psychology is introduced with particular emphasis on tenets specifically relevant to the overall thesis, such as adaptation, fitness, threat survival, group living and cooperative alliances, all of which, it will be argued, are affected by caffeine ingestion.
- Since the proposed caffeine model is underpinned by the body's ancient physiological response to threat, an evolutionary model of threat and stress-arousal is required. Such a model is suggested here, and offered for scrutiny. This model, the survival enhancement model examines plausible phylogenetic underpinnings of modern behaviours observed in response to stressors. Two dimensions, 'level of perceived threat' and 'level of perceived controllability', are integral to the model. Arguably, these two dimensions are able to account for and predict *specific* threat-related behaviours such as death-feigning or trauma paralysis, fight or flight syndrome behaviour, post traumatic stress disorder (PTSD), suicide, appeasement behaviours and species-specific stress-arousal diffusion behaviours, such as grooming, verbal exchanges and tend-and-befriend behaviours, together with more *general* threat-related behaviours such as heightened vigilance and increased caution.
- A model of the behavioural effects of caffeine use is developed, demonstrating that caffeine use taps into part of the body's phylogenetically ancient response to perceived threat. In so doing, it is argued that caffeine elicits the release of bodily resources which, under no caffeine conditions, are elicited by physiologically ancient threat-survival behavioural strategies. The caffeine model is underpinned by known physiological processes and theory and based on documented effects of caffeine from extant and novel research findings. The predictive power of the model is tested through empirical studies.

In order to support the hypothesis that moderate caffeine use promotes adaptive behaviour, it is necessary to show that the behavioural effects of ingesting caffeine are specific, rather than general, and that these specific effects are such that individually and together they increase the probability of surviving. Of the 'hostile forces' described by Darwin, attacks by rival groups of conspecifics have proved to be one of the most prolonged and serious threats to *Homo sapiens*. In this context, a substance such as

caffeine, which increases arousal, has the potential to improve life expectancy. It is conceded that 'arousal' is a generalised state but since, as is discussed in Chapter Two, no consensus on the meaning or measurement of this term has yet been reached, it appears to be more fruitful to examine the behavioural effects of changes in the state of general arousal, rather than to make further attempts at defining this elusive term.

From a modern perspective it is almost certainly impossible to imagine the experience of the 'hostile forces' referred to by Darwin, that our distant ancestors routinely faced. Perhaps the closest modern man is able to get to such experiences, apart from living in a war zone, is to consider anthropological studies of Native Americans. Irwin (1994) describes such individuals as having exceptionally sharp eyesight, acute hearing, an acute sense of smell, and as being fast and accurate in their identification of flora and fauna, skilled at tracking, constantly vigilant and wary, able to endure physical hardship and fleet of foot. There is perhaps nothing very surprising here: the sooner one becomes aware of a potential threat and the earlier that threat is identified, the better the opportunity for evasive action and the greater the probability of survival. However such a description, within the context of the present thesis, suggests concrete hypotheses, through which the notion of caffeine use as promoting adaptive behaviour may be evaluated. Hence, for caffeine use to be seen as eliciting adaptive behavioural change, it is necessary to show that its use results in quantitative and qualitative changes in visual perception (vision being the primary sense of *Homo sapiens*), leading to faster responses and more accurate understanding of the visual environment; increased vigilance and wariness; faster distancing from a perceived threat and increased endurance. In addition, since adaptive behaviours spread within populations, it is necessary to demonstrate increasing caffeine use over time.

Empirical studies relating to the present thesis test whether caffeine ingestion facilitates processes presumed to underpin the early identification of potential threat. Since humans rely primarily on vision to monitor their environment, the empirical research studies focus primarily on caffeine's effects on different aspects of visual perception (though it is acknowledged that previous research demonstrates caffeine has the potential to affect all senses tested). Specifically, the effect of caffeine ingestion on the cognitive processes inferred to underlie execution of specific tasks is examined. All tasks examined involve cognitive processes central to the monitoring and perception of

novelty, and hence potential threat, in the environment. The tasks include seriation (three different sorting tasks: colour, odd/even, median split); speed of processing (numerical and verbal); figure-ground discrimination (picture and abstract shape embedded figures); global and local processing; four kinds of visuo-spatial ability (mental rotation, mental jigsaw, mental paper folding, mental superimposition of one image upon another); verbal fluency; the standard Stroop test and a specially developed 'phobic' version of the Stroop test. In addition, subjective measurements of psychological stress and physiological arousal are taken. There is particular emphasis on the ability to manipulate images mentally, as is required in tests of visuo-spatial ability, since image manipulation underpins object identification and object identification processes are inherent in the understanding of the visual environment and the perception and evaluation of potential threat.

The effect of caffeine use on broader patterns of behaviour is also examined. In situations of potential danger a high level of cautious or wary behaviour is likely to be appropriate. In personality theory habitual behaviours are referred to as traits but, when level of caffeine use has been correlated with a number of established personality traits, no clear picture has emerged, although anxiotics have been shown to avoid caffeine (Rogers 2007). However, the personality trait of 'venturesomeness' appears not to have been evaluated previously in this way and it may be useful to do so, on the basis that venturesome behaviours may be considered risky behaviours, which are generally not conducive to threat survival. If, as is being argued here, caffeine use increases the perception of threat, a negative correlation between level of caffeine use and level of venturesomeness would offer tentative support for the notion that caffeine use elicits defensive, threat-survival strategies: in an unsafe environment cautious behaviour may enhance survival chances. Hence caffeine use and the psychological trait of venturesomeness is examined.

Adaptations and adaptive behaviours may be considered multi-layered: whether the adaptive change is obviously physical, as for example in the shape of a bird's beak, or behavioural, as for example in the building of structures to defend against bad weather, cognitive changes must presumably be involved, together with changes to the many presently largely unknowable neuronal substrates of thought and action. A stronger beak that occurred by chance would be of little benefit to a bird which continued its

prior feeding behaviour, rather than taking advantage of the extra reserves of food the 'new' beak gave access to. Adaptive behaviours are copied and in some cases refined, as in the case of a female Japanese monkey's troop who, in 1953 was observed to wash sweet potatoes in fresh water before eating them. Ten years later the behaviour had spread to almost every member of the troop and the technique refined to washing the potatoes in sea water (Kawai 1963).

As illustrated above, adaptive behaviours spread throughout populations. Since it is being argued that moderate caffeine use in adults promotes adaptive behaviour, data to show a 'spread' in terms of both number of individuals using caffeine and amount of caffeine ingested daily, may be seen as tentative support for the thesis. If higher levels of caffeine use are found than previously recorded, the concept of spread is tentatively supported. Accordingly, a survey of current caffeine use is made.

Although there is presently no model of caffeine's overall effects in the literature, apart from the one being developed here, Lorist (1995) put forward a valuable model of caffeine's effects on human information processing. Since all new knowledge owes a debt to previous knowledge, Lorist's model is evaluated through theory and extant and novel experimental findings for its explanatory and predictive power.

Thus the primary focus of the present project is to develop and evaluate a comprehensive model of the effects of caffeine use. In order to do this a variety of theoretical perspectives are engaged with, including those of cognitive, pharmacological and evolutionary psychology. During the early stages of the research process the remarkable concordance between the documented effects of caffeine and the effects of stressors became apparent, a concordance which is examined in detail in the following chapter. Hence the novel notion that caffeine use elicits threat-related behaviours emerged from extant research data, necessitating development of an evolutionary survival enhancement model perspective of stress-arousal. The new caffeine model is evaluated on the basis of whether caffeine ingestion enhances or elicits behaviours which are likely to increase survival chances, whilst having no effect on other theoretically similar behaviours, which do not. New empirical studies of caffeine usage and personality and caffeine's effects on cognition and visual perception are used to test these hypotheses.

It will be argued that human evolutionary theory offers the most compelling conceptual framework for the model of moderate caffeine use as promoting adaptive behaviours, and that changes in patterns of neural regulation, as explicated in Polyvagal Theory (Porges 1995; 2008), provide an appropriate organizing principle for behavioural change observed under both threat and caffeine ingestion. Polyvagal Theory offers a precise mechanism through which perceived change in the environment is transmuted into appropriately mediated behaviour, for example, attentional focus is switched from peripheral to focal and motivational focus from promotion to prevention.

1.2.1. Empirical Investigation

It will be argued that moderate caffeine use in healthy adults promotes adaptive behavioural response in a situation of perceived threat. In order to evaluate this thesis, both theory and novel research data are utilised.

The research element of this project consists of eleven inter-related quantitative studies, utilizing experimental, correlational and survey methods:

- Levels of caffeine use: levels of caffeine use in young adults of reproductive age, for which there are presently no data available, were ascertained, following the development and piloting of an appropriate survey instrument (study 1).
- Caffeine use and personality: caffeine use was correlated with established personality traits, evaluating the present hypothesis that caffeine use is related to increased wariness, or security monitoring (study 2).
- Caffeine and input/output processes: the theoretical contention that caffeine ingestion affects only input and output processes (Lorist 1995) was evaluated through performance on a variety of cognitive tasks: (i) three types of card sorting (experiment 1), (ii) speed of processing in verbal processing and (iii) speed of processing in numerical processing (both evaluated in experiment 2).
- Caffeine and central processing: the theoretical contention that caffeine ingestion does not affect central cognitive processing (Snel and Lorist 1998) was evaluated utilising changes in attentional focus, demonstrated through a local and global processing task. Subjective stress was measured through the Stress Arousal Check List (experiment 3).

- Changes in visual field dependence-independence together with inferred change in motivational focus were examined: evidence for qualitative, as well as quantitative changes in central processing was evaluated, utilizing the mediating mechanism of motivational focus, in two embedded figures tasks (experiment 4).
- Caffeine and fear-inducing stimuli: caffeine's effect on the standard Stroop and a newly developed and piloted version of the Stroop test, based on common phobias ('phobic Stroop') was evaluated (experiment 5).
- Caffeine and object identification: the ability to rotate an object mentally underlies the ability to identify objects seen from different perspectives or which are partially occluded. Mental rotation was evaluated using four kinds of tests requiring the ability to rotate and manipulate mental images (experiments 6, 7, 8 and 9).

It is argued that novel empirical data, obtained from experiments reported here, in which caffeine ingestion is the independent variable, measure a sufficient subset of behaviours implicated in threat identification, and hence threat survival, to make an accurate, if tentative, evaluation of the thesis that moderate caffeine use promotes adaptive behaviours. All studies were carried out with the approval of the departmental Ethics Committee and all participants gave informed consent.

1.2.2. Overview: Perspectives and Causal Mechanisms

The following section gives an overview and introduction to the theoretical perspectives and causal mechanisms, which are considered or invoked in the development of a new model of caffeine use.

1.2.2.1. Perspectives on the Use of the Drug Caffeine

Since the aetiology of drug abuse has been studied through a variety of perspectives, it is unsurprising to find that a variety of theoretical perspectives has been utilized previously in attempting to address the enigma of caffeine use and its effects on behaviour. For example, caffeine has been studied through the perspective of the social psychology of drug taking, through the perspective of pharmacology and through the cognitive-perceptual perspective. Although each of these perspectives is valuable, as will be seen from the brief summaries below, it will be argued that an evolutionary psychology perspective is able to offer the most compelling account of caffeine use.

Caffeine is a drug and constitutes class five of drugs of abuse, as defined by the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV) (APA 1994). The main entries in DSM-IV for caffeine relate to caffeine intoxication, caffeine-induced anxiety disorder and caffeine-induced sleep disorder, together with caffeine-related disorders not otherwise specified, for example caffeine withdrawal/physical dependence. James (1997), in his biobehavioural analysis, is sceptical as to how frequently the criteria for caffeine intoxication are met empirically. Five or more of the following symptoms need to be present, to the point of causing clinically significant distress or impairment to social or occupational functioning, after other medical conditions have been discounted: restlessness, nervousness, excitement, insomnia, flushed face, diuresis, gastrointestinal disturbance, muscle twitching, rambling flow of thought and speech, tachycardia or cardiac arrhythmia, periods of inexhaustibility and psychomotor agitation.

Though there may be doubt about the reality of caffeine intoxication, there is no doubt about the reality of caffeine toxicity. It is, however, quite difficult to ingest a lethal dose of caffeine (typically 5g: Kerrigan and Lindsey 2005) through normal, beverage-based, caffeine use and most cases of accidental poisoning involve children administered multiple caffeine-containing medications, or atypical ingestion. An example of atypical ingestion in a near fatal case is that of a man who, was admitted to hospital in an unconscious state, and later found to have ingested 500g of ground coffee, probably containing about 15g of caffeine, apparently because he wanted to get 'high' (Wurl 1994). However, fatal caffeine overdoses are not unknown: Kerrigan and Lindsey's 2005 paper reports two, the first a 39 year old female with a history of intravenous drug use, the second a 29 year old man with a history of diabetes and obesity. Holgrem, Norden-Pettersson and Ahlner (2004) report a further four cases of fatal caffeine overdose.

A diagnosis of caffeine-induced anxiety would necessitate symptoms of prominent anxiety, panic attacks, obsessions or compulsions, whilst a diagnosis of caffeine-induced sleep disorder requires sleep disturbance sufficiently severe to warrant clinical intervention. Both sets of symptoms need to be associated with caffeine intoxication or withdrawal, to impair everyday functioning and not to be attributable to other medical conditions and are, apparently, rare (Sussman and Ames 2001). Caffeine withdrawal *per*

se is not included in DSM-IV, although Hughes, Oliveto, Helzer, Higgins and Bickel (1992) argue that it should be, on the basis that there is more empirical data supporting caffeine withdrawal as a specific syndrome than there is for the other caffeine related disorders included in DSM-IV.

There is an extensive and burgeoning literature concerned with theories of drug use, but it is beyond the scope of the present work to attempt a comprehensive review of these many different theories: however a brief introduction to those approaches deemed most relevant to the present endeavour, the use and effects of caffeine, will be made.

1.2.2.2. Perspectives from Social Psychology

Sussman and Ames (2001), in their social psychological review of models of drug abuse, consider the risk and protective factors model, biopsychosocial models, problem behaviour, hedonic treadmill, the triadic influence model and functional meanings theory. Of the risk factors identified by Sussman and Ames, genetic predisposition, poor social and coping skills, social influence and unstructured time apply as much to caffeine use as to other drugs. Biopsychosocial models attempt to group risk and protective factors into, for example, specific neurobiological, psychobehavioural and socio-environmental arrays, arguing that it is the complex and dynamic interaction of factors which has predictive power (Johnson and Pandina 2002). Problem behaviour theory, developed by Jessor and Jessor in the nineteen seventies, is considered a comprehensive and compelling psychosocial explanation of adolescent behaviour (Steinberg and Morris 2001) in which the adolescent drug user aims to break society's rules and, as such, is not especially applicable to caffeine use. The hedonic treadmill argument is, simply, that drug use provides a way to *'feel good very quickly'* (p. 88) and, since the user seeks to feel good and enjoy pleasure when the effect of the drug wears off, action is taken to recapture the pleasing experience (Weiner, Sussman, McCuller and Lichtman 1999). Triadic influence theory is an integrated model developed by Petraitis, Flay and Miller (1995) from a review of fourteen multivariate theories of drug use. The triad of influence is derived from cognitive-affective theories (interpersonal), social learning theories (attitudinal/cultural) and commitment and social attachment theories (intrapersonal), all of which are applicable to caffeine use. Functional meanings models attempt to understand drug use through discovering what function, or meaning, use of the drug supplies. For example, in our culture, drinking

cola together may be seen *symbolically* and *ritualistically* as a way of marking friendship, and cola, tea and coffee are used *recreationally to promote social interaction* (Pickering and Stimson 1994). In addition, the stimulant properties of caffeine may have a *utilitarian* purpose for shift workers or others needing to boost their levels of alertness or a *medical* use to relieve hunger, fatigue, pain, promote weight loss or improve mood (Sussman and Ames 2001). Both of the latter two contentions are applicable to caffeine use.

In essence, all the above theories can be seen as arguing that drug use, for the individual concerned, is in some way beneficial, which may partly explain the difficulties drug reduction programmes encounter. Warburton (1998), in relation to social drugs such as caffeine and nicotine, argues for a functional model in which the substance of choice is used as a 'tool' or 'resource', providing psychological and behavioural benefits with which to address the demands of everyday life. The affective, cognitive and behavioural benefits are mediated through the regulation of neural mechanisms (Nehlig 2004), which modulate central arousal processes, enabling individuals to cope better with the demands of a given situation. If, as the above theories suggest implicitly, caffeine use may be perceived as helpful in difficult situations, this may explain the long and intimate relationship between ourselves and the substance. However, none of the above theories of drug use is specific to caffeine and none attempts to predict the behavioural effects of caffeine explicitly.

1.2.2.3. The Pharmacological Perspective

Caffeine, one of a family of methylanthines, also known as trimethylxanthine, is very well absorbed from the gastrointestinal tract into the bloodstream and passes through all biological membranes, including the blood-brain and placental barriers. Caffeine was first isolated from coffee beans in 1820 by Runge, though its chemical structure was not identified until 1875 (Arnaud 1984). The stimulant effects of caffeine derive from its propensity to bind to adenosine receptor sites (specifically A1 but not A2 receptors: Huang, Qu, Eguchi, Chen, Schwazschild, Fredholm, Urade and Hayaishi 2005) where adenosine would otherwise inhibit the release of neurotransmitters, including excitatory glutamate and dopamine (Solinas, Ferre, You, Karcz-Kubicha, Popoli and Goldberg 2002), which act on the central nervous system (CNS).

The nervous system consists of two major components, the CNS, comprising the brain and spinal cord and the peripheral nervous system, made up of nerve complexes that lie outside the central region. The peripheral nervous system consists of the somatic and autonomic systems, and the autonomic system is further subdivided into the sympathetic and parasympathetic systems. It is primarily the sympathetic nervous system which controls the physiological and psychological changes underlying the behavioural changes seen after caffeine ingestion, largely through increased arousal brought about by changes in the release of neurotransmitters such as norepinephrine, epinephrine, acetylcholine and glutamate, caffeine bringing about these changes through its ability to bind with and block adenosine receptors. Since adenosine normally inhibits the release of neurotransmitters such as glutamate and dopamine, the result of caffeine's interference is to increase the release of these neurotransmitters and hence increase excitation (Kalmar and Carafelli 2004). In addition, the hypothalamus acts on the endocrine system to release hormones that influence autonomic function. A number of studies show increased autonomic and cortical arousal after consuming caffeine (e.g. Barry, Rushby, Wallace, Clarke, Johnstone and Zlojutro 2005). Specifically, caffeine's effects on cortical arousal (Van Dort, Baghdoyan and Lydic 2009) and autonomic arousal (Quinian, Lane, Moore, Aspen, Rycroft and O'Brien 2000) are well documented.

The brain uses many chemicals as neurotransmitters and neuromodulators and each of the widely investigated neurotransmitters has a number of receptors. For example, acetylcholine has at least four types of nicotinic receptors, and five types of muscarinic receptors (Servent and Fruchart-Gaillard 2009), the latter being one of several kinds of receptors affected by caffeine. Dopamine has at least five families of receptors (Contreras, Fouillioux, Bolívar, Simonovis, Hernández-Hernández, Armas-Hernández and Velasco 2002), serotonin seven families (Roth 2007) and at least eight subreceptors of glutamate (Gereau and Swanson 2007). Even in our limited state of knowledge about neuromodulators and neurotransmitters an extremely complex picture emerges of an almost infinite number of possible patterns of excitation and inhibition. Necessary and valuable though an understanding of the pharmacology of caffeine is, at present it is not possible to tie changes in patterns of neurotransmitter excitation and inhibition to changes in behaviour. For example, pharmacology offers a useful explanation of the increased arousal seen after caffeine ingestion, which is a plausible explanation for

improvements in sub-optimal performance, but is unable to offer a rationale for why increased arousal affects only some behaviours, in some circumstances. Hence, though pharmacological accounts are necessary, they may not be sufficient and it is considered inappropriate to base a model of the behavioural effects of caffeine solely on a pharmacological account, since it is presently not possible to make specific predictions of the effects of caffeine through this perspective.

1.2.2.4. Cognitive and Human Information Processing Perspectives

The cognitive perspective on human behaviour seeks to model, through inference, mental processes underlying perception, memory, attention, problem solving, emotion and language, all of which are affected to a greater or lesser degree, under some circumstances, by the ingestion of caffeine. With regard to drug-taking, specifically caffeine use, Lorist (1995; 1998) has developed a cognitive model, which attempts to predict the behavioural effects of caffeine (Figure 1-1) and is seen as making a valuable contribution to the research record. The model distinguishes three functionally different structural processes: input (feature extraction, stimulus identification), central processes (serial comparison, binary decision, response selection) and output (response preparation, response activation, response execution), utilizing cognitive theory and evoked response potential (ERP) data. However, the extent to which the three structural stages are in reality separate is unclear (p. 5). Lorist (1995) states that ‘... it remains unclear which specific mental processes are influenced [by caffeine]’ (p. 4) and that it is presently not possible to take account of caffeine’s positive and negative effects on different cognitive processes, such that an experimental finding of ‘no effect’ may indeed demonstrate no effect of caffeine, or alternatively may conceal positive and negative effects on different sub-processes, which cancel each other out.

Additionally, Lorist concedes that it is difficult to ‘disentangle ... the mental functions’ (p. 4) involved in any specific cognitive task. She cites Gaillard’s (1988) list of mental functions (or stages of information processing) that he perceives might underlie the Digit Symbol Substitution Test: ‘encoding of symbols, memory processes, central processes of exchanging digits into symbols, selective attention, control of eye movements, motor processes and motivation’ (p. 4). Any or all of these stages may be affected differentially by caffeine ingestion. In the light of the attempts by researchers in artificial intelligence to simulate human perceptual and cognitive performance, or even

with respect to a consideration of production system models, it is clear that each of Gaillard's stages is likely to subsume several (presently unknown) intermediary processes, each of which again may be affected positively or negatively by caffeine. This problem, that is, developing an accurate 'flow chart' of all the sub-processes and rules available at each alternative step of information processing, appears to be intractable in our present state of knowledge.

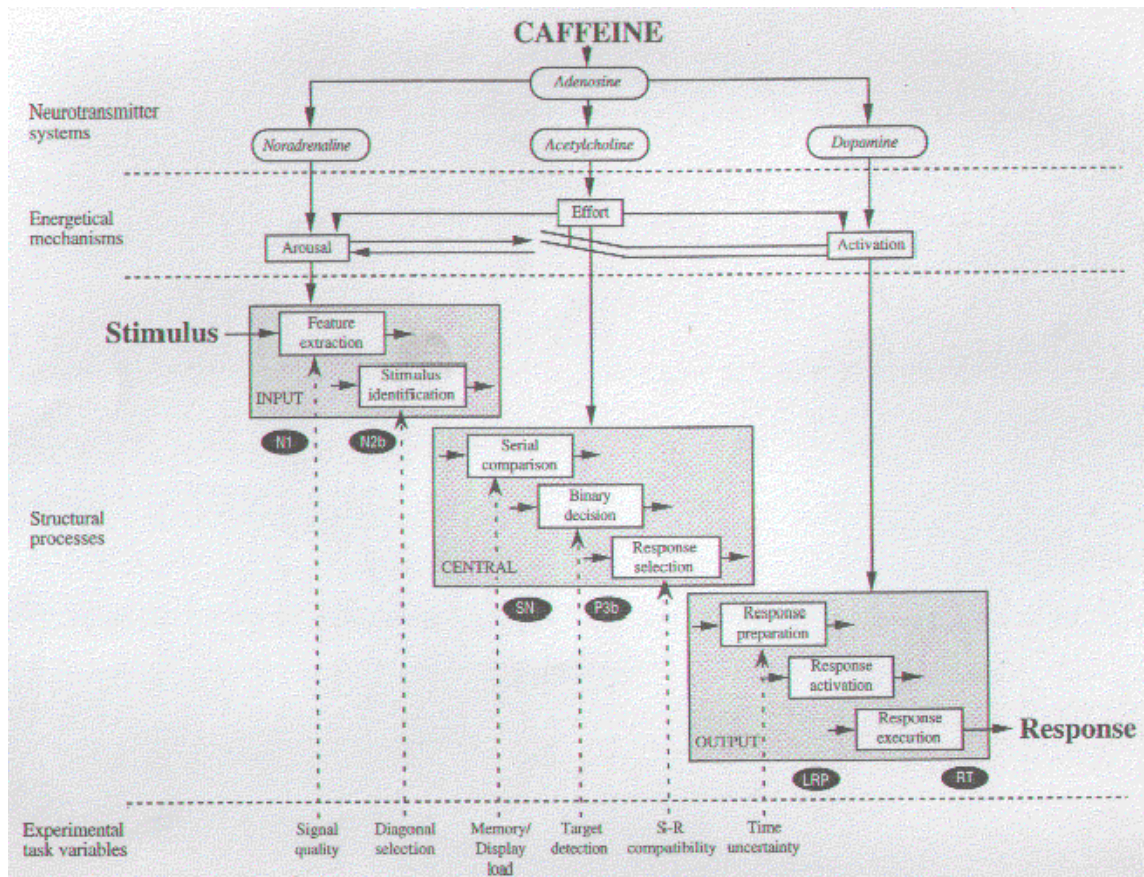
Lorist, however, makes some attempt to do this (see Figure 1-1), though clearly the main thrust of her interest and research concerns the three structural processes described above. The first level of Lorist's model, 'neurotransmitter systems', shows caffeine affecting adenosine, which in turn affects levels of noradrenaline, acetylcholine and dopamine. However, an analysis based on neurotransmitters, though useful, is not sufficient to differentiate between behaviours. In Lorist's model, the 'neurotransmitter systems' level affects the second level, 'energetical mechanisms', which consists of 'arousal', 'effort' and 'activation'. These latter are shown as affecting the three structural processes, the main foci of Lorist's research, which in turn are mediated by experimental task variables, though how and in what way is still unclear.

It will be argued here that a more detailed exploration of energetic mechanisms is crucial in attempting to understand caffeine's disparate effects on performance. Lorist argues that arousal is a phasic physiological response to input affecting perceptual orienting and processing, and further states that 'activation' affects control and co-ordination of motor actions whilst 'effort' co-ordinates both 'arousal' and 'activation' when 'these mechanisms are in a sub-optimal condition...' (p. 7). However, how this sub-optimal state is countered by effort is again unclear.

A number of information processing theories argue that there are multiple energetical mechanisms and Lorist states that she has drawn on Hockey, Coles and Gaillard (1986), Mulder (1986), Pribram and McGuinness (1975) and Wickens (1991) in support of her model. Although conceding that the effects of drugs, including caffeine, are widely believed to be mediated by the effects of energetics, Lorist appears to have restricted her study of the effects of energetics largely to experimental manipulation of some attribute variables, such as fatigued/rested, old/young and mood state. Given that the focus of Lorist's research with caffeine appears to have been on the structural processes

involved, this restriction may well be appropriate. However, it will be argued here that the cognitive Human Information Processing account is unable to give sufficient weight to the psychological and physiological processes through which caffeine-induced arousal is transmuted into behavioural change, since the mechanics of information processing are currently largely unknowable.

Figure 1-1: Lorist's (1995) Cognitive Model to Predict the Behavioural Effects of Caffeine Ingestion



Additionally, it is argued that such an approach is unable to incorporate, in the sense of providing a potential explanatory framework, a wide range of previously apparently contradictory and paradoxical research findings. For example, Lorist's definition (Snel and Lorist 1998) of energetic mechanisms as mechanisms which mediate the intensity of the performance of information processing, whilst the structural demands of the task remain unchanged, appears unable to explain why these effects do not apply to all cognitive tasks. It is argued that variance in 'intensity of performance' does not do full justice to the range of qualitative and quantitative changes seen in performance under the influence of caffeine and is considered insufficient to account for the ambiguities

and conflicts extant in the research literature. Lorist's primary conclusions are that 'caffeine specifically affects input and output related information processing mechanisms' (Lorist 1995 p. 29) but that 'caffeine has no effect on the processing of non-spatial stimulus features' (Snel and Lorist 1998 p. 200). In fact a number of non-spatial stimulus features, such as colour, have been shown to be affected by caffeine. For example, Ruijter, De Ruijter and Snel (2000) found an interaction of colour, when using red and blue stimuli, and caffeine condition; Gupta and Gupta found effects of caffeine on kinaesthetic after effects; and Gupta found effects of caffeine on conceptual and acoustic tasks (in Gupta and Gupta 1999). A cognitive account of the area under study, such as Lorist's, though valuable is deemed in our present state of knowledge of cognitive mechanisms, to be insufficient.

1.2.2.5. The Evolutionary Perspective

Barrett, Dunbar and Lycett (2002) argue that cognitive psychology is 'the parent discipline' (p. 10) of evolutionary psychology in that the focus of evolutionary psychology is to identify and test domain specific cognitive modules or mental algorithms, which have developed over evolutionary time due to specific selection pressures (for example, the 'cheater detector' identified by Cosmides 1989). In contrast, human behavioural ecology, whose parent disciplines are zoology and behavioural ecology, focuses on identifying and measuring differing behavioural strategies, which result in differences in reproductive success. There are a number of other important and inflammatory differences between these two divisions, which are discussed more fully in Chapter Three, but from the perspective of the present thesis it seems appropriate to echo Barrett, Dunbar and Lycett's argument that there are many important questions that cannot be answered using either the evolutionary psychology or the human behavioural ecological approach alone, but which require the application of both approaches together. In an avowed move towards unification, these authors prefer the term 'human evolutionary psychology', which appears to be a useful approach. In the everyday world there are many challenges to face: there may, or may not be, for example, a specific 'vigilance' module within the brain detecting such challenges, as opposed to more generalized cognitive and perceptual machinery, but in either case appropriate behavioural strategies are selected and acted upon.

The primary challenge facing an organism is that of survival, or staying alive (Campbell 2002). Darwin (1859) preferred the phrase Struggle for Existence, by which he meant not only the survival of the individual organism, but also the leaving of viable progeny. Darwin was not the first to notice that all species are capable of producing more than enough offspring to replace themselves, but he was the first to offer a plausible explanation for how such apparent profligacy will benefit some individuals differentially and ultimately may lead to the development of new species. He argues eloquently that the environment in which organisms find themselves affects their chances of survival and that, since individuals are not identical, some will prosper more than others in any specific environment. Those organisms which prosper are likely to leave more offspring than those which fail to thrive. He goes on to state that ‘This preservation of favourable variation and the rejection of injurious variation, I call Natural Selection’ (pp. 130-1) and that ultimately the accumulation of many small favourable variations as opposed to injurious variations will result in speciation.

Dunbar (1982: 2007) summarises the theory of natural selection in just three premises: The Principle of Variation states that all individuals of a particular species show variation in their phenotype, that is in their behavioural, morphological or physiological traits; the Principle of Inheritance states that some part of these variations will be heritable; and the Principle of Adaptation states that some of these variants will confer an advantage in the acquisition of important resources, such as food, shelter and mates. Hence the possessors of favourable variations, or adaptations, are likely to out-compete their contemporaries for resources, leaving more progeny, some of whom will also have the advantageous trait. A simple example of this process is seen in variations in fur colour: a prey animal whose fur colour provides effective camouflage in its environment has a greater chance of survival in that specific environment and of successfully passing on its genes than its siblings and contemporaries, whose fur colour blends less well with their background. Similarly, a prey animal that is quicker to see, hear or smell a predator, or is fleet of foot or better at concealment than its siblings and contemporaries will also have a greater than average chance of survival.

Self evidently, any species which presently exists has developed a sufficiently robust repertoire of survival strategies to address successfully the challenges, or vagaries of nature, which exist in its present environment. However, environments are not static but

subject to change: some changes, such as climate variation, may be relatively slow whilst others, such as the approach of a predator, may be very sudden. In order to continue its existence an animal must continuously monitor its environment for potential threat and, when threat is perceived, take evasive action. It is logical, therefore, to expect that a substantial proportion of an animal's cognitive and perceptual abilities subsume the monitoring of perceived threat, whether the environmental change is a direct threat to survival, as in the case of a predator, or a threat to an individual's resources from members of the same species or social group. In fact this is the case: the survival imperative supersedes all others, at least until viable progeny have been produced, in most animals, human or otherwise. Although there are a small number of 'exceptions' to the survival imperative (for example heroically altruistic deaths, martyrs and suicide bombers which are discussed further in Chapter Three) the focus of the present thesis lies in a consideration of the underpinnings of perceptual and cognitive threat-monitoring processes and the extent to which caffeine ingestion may facilitate or inhibit such processes.

The extent to which potential threat is monitored effectively has substantial influence over an animal's survival chances, so it is not unexpected that complex physiological structures and behaviour patterns are found to be implicated in the monitoring process. Although it cannot be said definitively that sight, smell and hearing developed as means of identifying potential threat, clearly impairment of these senses, relative to conspecifics, is likely to reduce an individual's survival chances, and all play an important part in threat monitoring. In addition to the anatomical structures and behavioural strategies for monitoring potential threat, there is a cascade of physiological change, such as the flight-or-fight syndrome, which provides additional resources for dealing with perceived threat. Subjectively, the cognitive and emotional processes of monitoring for potential threat are experienced as stressful, though generally a threat that is perceived as clear and direct (and hence amenable to identification and defensive action) is experienced as less stressful than threat perceived as vague or diffuse. It seems highly probable that what is today experienced as 'stress' is the engagement of an ancient and powerful threat-monitoring system: we may no longer routinely face attack at a physical level from wild animals or hostile conspecifics (except in situations of war), but at a social level we may still be 'stabbed in the back' or 'eaten alive' by 'friends' and colleagues. Those groups of individuals who do routinely face potential

and actual physical threat, such as the police and the armed forces, face high levels of stress-related illness. Cox (2003) has pointed out that stress is a perceived threat to both physical and psychological well-being, but equally potential threat is a stressor *per se*.

It will be argued, from within the perspective of human evolutionary psychology, that the survival imperative shapes most of what we think and do, on an everyday basis, to an extent that is not generally appreciated or articulated. Hence the thesis is heavily embedded within the theories and research findings of the evolutionary approach to understanding human behaviour in general and responses to threat and stressors in particular.

In order to support the survival imperative, substantial physical, cognitive and emotional resources are devoted to monitoring, identifying and evading potential threat. Many of these responses are generally studied under the concept of 'stress'. However, as will be explored more fully in Chapter Three, there are difficulties with the operationalization of the concept of 'stress': in response to a stressor or potential threat, the brain and body are suffused with massive physiological change, which depresses some bodily systems whilst enhancing others, all seemingly initiated by the perception of environmental change (and hence potential threat) and subsequent increase in bodily arousal. Some of these changes have been encapsulated in the phrases 'flight-or-fight syndrome' or 'attack and escape behaviours', but the term preferred here is 'survival enhancement syndrome' (SES), since the two former phrases, though good descriptions of parts of the overall response, are unable to capture the full spectrum of the shift in perceptual, emotional, cognitive and physiological change that is invoked by the perception of environmental change.

1.2.3. Inferred Mechanisms through which Caffeine Ingestion Mediates Behaviour

Judging by the substantial body of research findings available, there are few problems in demonstrating that caffeine ingestion affects behaviour. However, identifying and illustrating any of the, presumably many, intervening mechanisms is more problematic. It is suggested that the mechanisms through which moderate caffeine use promotes adaptive behaviours may be viewed at a macro level, that is, the triggering of the survival enhancement syndrome, at the behavioural level by examining specific changes in behaviour, such as 'flight or fight' behaviour, changes in visual processing and

changes in motivation at the cognitive level and by invoking the concept of production systems and at the micro level by considering the effect caffeine has on, for example, neurotransmitter systems and patterns of neural organization. An overview of some of these mechanisms is given here and each of these levels of analysis is considered in more detail in subsequent chapters.

1.2.3.1. Increased Physiological Arousal

Inherent to the study of caffeine's effects (and to the study of many other phenomena), is the concept of arousal. Despite the concept's long history in psychology and physiology, a satisfactory definition and consensus on measurement have yet to be reached. Although everyone seems to know what, in general, is meant by the term arousal, the term defies precise definition and the many physiological indicators of the concept fail to correlate with one another, still less with other subjective measures.

One approach to solving the difficulties inherent in the concept of arousal was suggested by Hockey (1984), who developed a taxonomy of stressors, in which a number of events known to affect arousal, such as amphetamine and alcohol ingestion, noise and sleeplessness are rated as having positive, negative or no effect across five aspects of cognition: 'general alertness', 'attentional selectivity', 'speed', 'accuracy' and 'short term memory capacity' (STM). Although this approach has merit and is useful in some circumstances, it fails ultimately both because the kinds of stressor, for example, 'noise', can be subdivided almost infinitely (into different kinds of noise) and because the cognitive classifications, for example 'STM', subsume a whole range of sub-processes, which may be affected differentially by any stressor. As Matthews, Davies, Westerman and Stammers (2000) sagely remark, 'the endpoint of the cognitive critique [of arousal theory] might be an exceptionally detailed description of stressor effects completely resistant to any attempt at explanation' (p.167).

Where does this leave the concept of arousal? In 1980, Norman, when delineating important but unresolved issues in cognitive psychology, made the point that human behaviour results from an interplay of cognitive and biological activity and that much of the activity of the cognitive system is determined by the needs of the biological regulatory system. Yet, as Matthews, Davies, Westerman and Stammers note '...most

of cognitive psychology focuses on the Pure Cognitive System and virtually ignores the key role played by the [biological] Regulatory System' (p.18).

Cognitive psychology, especially cognitive neuroscience, has embraced a wide range of techniques which permit the study of brain function, such as event-related potentials (ERPs), positron emission tomography (PET), magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI), magneto-encephalography (MEG), transcranial magnetic stimulation (TMS) and repetitive transcranial magnetic stimulation (rTMS), which have greatly extended our knowledge of brain areas involved in different cognitive functions, but not as yet of specific processes. Typically this knowledge is derived from changes in brain activity during one (or possibly two) particular cognitive tasks chosen by the researcher, so opportunities for applying these valuable insights to everyday life, during which we are often engaged in many tasks simultaneously, are presently somewhat limited. Unfortunately these demonstrations of brain activity, though useful, are unable to throw light on presumed underlying changes in arousal.

A different approach to arousal is contained within the more general and perhaps better known models of stress and arousal, such as the Yerkes-Dodson Law (Yerkes and Dodson 1908) and the Easterbrook hypothesis (Easterbrook 1959), which were developed before the 'cognitive revolution' of the 1960s and the 'biological revolution' of the 1990s. However, neither has fared especially well under modern scrutiny, since by current standards both models are underspecified. Neiss (1988) commenting on the term coins the phrase 'arousal's reign of error', arguing persuasively that both the constructs of arousal and the hypothesis of an inverted-U relationship between performance and arousal be abandoned, though it is not clear what concept would replace that of arousal. However, there are examples where performance on specific tasks offers limited support for arousal theory. For example, following reviews of dual task performance, both Eysenck and Hockey conclude that arousing stressors have 'a *relatively* more facilitative effect on primary than on secondary task performance' (Matthews, Davies, Westerman and Stammers 2000 p. 167).

On the other hand, in ERP studies and electroencephalography studies (EEG) of vigilance no such support is found. Parasuraman (2000), in a 45 minute visual vigilance

task, recorded four ERP components, N100, P200, N250 and P300, and so was able to analyse correct detections/rejections, false alarms and misses and concluded that the amplitude of late ERP components reflected the stages of decision processing of the task, rather than arousal. Further, Parasuraman argues that, although cortical arousal falls during a vigilance task (and during most other tasks, and during no task at all, over time), reduced cortical arousal is not a necessary prerequisite for a vigilance decrement, that is, cortical arousal is not a reliable measure of vigilance performance, though 'general arousal' seems to be so. Despite the problematic nature of arousal, particularly in relation to various physiological indicators, many of which show the effect of caffeine ingestion, it seems unlikely that the term 'arousal' will be abandoned until a consensus on an alternative term for the concept is found, so it is retained within this thesis.

1.2.3.2. Production Systems

In essence any perceived change in the environment is potentially threatening and hence arousing, until shown to be otherwise [although changes which are not noticeable, such as slow fades (Levin and Simons 1997), and those described in change blindness and inattention blindness research literature (Simons, Franconeri and Reimer 2000) are not]. Perception of change or novelty in the environment results in increased arousal, which has the effect of shifting behaviour, so that the organism is better prepared to survive the perceived threat. Caffeine, being a psychostimulant, also increases arousal (Childs and de Wit 2006) when it is ingested and hence also triggers a higher level of behavioural readiness, just as novelty does.

At the cognitive level, the sequence of events may be seen as an information processing production system (Newell and Simon 1972) of 'if-then' logical operators. In order to stay safe and alive, the environment must be monitored vigilantly. At the production system level, **if** novelty enters the environment, **then** an increase in arousal results. **If** there is increased arousal, **then** orientation to the sources of novelty is faster than during lower levels of arousal. **If** the novel stimulus is not immediately perceived as non-threatening, **then** longer scrutiny occurs, so that categorization may be made. **If** the novelty is categorized as non-threatening, **then** arousal falls to the previous level of relaxation. **If** it is not possible to categorise the novel stimulus, so that it continues to be perceived as potentially threatening, **then** greater scrutiny is undertaken through

attentional shift, from ambient to focal attention. **If**, following this scrutiny, the change to the environment is still perceived as unknown or potentially threatening, **then** there is a shift from promotion to prevention focus. **If** a prevention focus is assumed, **then** security and safety concerns predominate, which are operationalized through survival enhancement behaviours. A specific survival enhancement behaviour is arrived at on the basis of other, subsequent, production systems.

1.2.3.3. Polyvagal Theory

Production systems are important in endeavouring to understand, at a cognitive level, the decisions which lead to behaviour, but are somewhat remote from the ensuing activities. What is needed is a perspective which links the pure cognitive system and the regulatory system flexibly, over a wide range of behaviours. Polyvagal Theory (Porges 1995, 1997, 1998, 2001, 2008) appears to be such a framework.

Polyvagal Theory describes three levels of phylogenetically developed neural regulation, or three neurophysiological systems, associated with differing levels of perceived threat in the environment. The first level of neural regulation prevails when the environment is perceived as safe. The second level prevails when the environment is perceived as potentially unsafe causing a cascade of behavioural change, underpinned by physiological changes, some of which are known as ‘fight or flight’ or ‘escape and attack’ behaviours. The third level promotes ‘defence and avoidance’ behaviours, such as freezing or death-feigning and, in primates, communication and cooperative behaviours. The three psychophysiological states described in Polyvagal Theory may be seen, to some extent, as congruent with Faw’s (2006) ‘at ease’, ‘get ready’, ‘get set’ and ‘go’ analysis of the effects of neurotransmitters on brain function, or specifically on the mechanisms of cortical arousal and the neural correlates of consciousness. The Jacksonian principle (Jackson 1958) of dissolution applies within Polyvagal Theory in that lower, or phylogenetically older, nervous system structures are disinhibited when higher, or phylogenetically newer structures, are damaged or overwhelmed. Polyvagal Theory provides a comprehensive and compelling account of the effects of threat, stress and trauma on the body, to the extent that successful interventions for autism, post traumatic stress disorder (PTSD) and a range of developmental abnormalities have been reverse engineered from the theory. Polyvagal Theory also provides a large part of the

theoretical basis for the present thesis and consequently is discussed in more detail in the following chapter.

1.2.3.4. Observable Behavioural Shifts Under Caffeine Ingestion

Although the mechanisms described above are inferred, they underpin clearly observable shifts in behaviour. These shifts may be the result of caffeine ingestion, as demonstrated in the empirical work which follows, or the result of some other environmental stimulus which is arousing. Increased arousal and the accompanying inferred threat, brings about a number of shifts in behaviour (in addition to the well documented physiological changes associated with the ‘flight-or-fight’ response), such as faster orienting and longer inspection times, which have previously been identified in the research literature. The thrust of the empirical work supporting the present thesis is to demonstrate caffeine’s ability to shift behaviour to a mode which has the potential to enhance survival, in the way that the two previous examples do (for example, shifting visual processing from global to local) and where possible to demonstrate through a number of parallel experiments, the specificity of caffeine’s effects (for example, in relation to five tests of speed of processing, caffeine’s effects are seen only in one basic category sort).

1.2.3.5. Field Dependence-Independence Shift Under Caffeine Ingestion

In maintaining visual vigilance against potential threat the primary concern must be to discern whether in fact ‘anything’ is there: is the subtle interplay of light and shade simply that, or is ‘something’ out there? A standard test of the ability to see something which is less than obvious is to embed or ‘camouflage’ an item within a similar background: individuals able to identify the embedded figure are said to be ‘field independent’ whereas those less able to do so are described as ‘field dependent’. If a novel item or potential threat can be distinguished readily from its background, the perceiver has a better opportunity to take appropriate action and remain safe, whereas if the perceiver is unable to make this distinction he or she is at greater risk. Consequently, if caffeine is shown to shift individuals who are in a field dependent state pre caffeine ingestion to a field independent state post caffeine ingestion, this will be an example of an adaptive behavioural shift due to caffeine ingestion.

1.2.3.6. Visual Attentional Shift

When the environment is perceived as safe, a state of ambient attention prevails during which distant objects become subject to attentional gaze; when, however, the perception of potential threat occurs, visual attention shifts immediately to what is close at hand and therefore likely to be most immediately dangerous. Visual information processing is often described in terms of two levels: a dorsal/ambient (or preattentive or visuomotor) level and a ventral/focal (or attentive or cognitive) level (Fischer, Pannasch, Graupner, Helmert and Velichkovsky 2008), which, arguably, could be likened to altered states of perception, or 'perceptual shift'. The shift between these two processing streams is instigated by differing levels of arousal (Velichkovsky, Rothert, Kopf, Dornhöfer and Joos 2002).

In differentiating between these two types of visual attention, the distribution of fixation durations and the amplitude of saccadic movements become critical. It has been found that fixations from 90-140 ms produce large saccades beyond the parafoveal region of the retina, hence targets are not seen as individual items, whereas fixations longer than 140-200 ms are related to focal processing (Pannash, Dornhöfer, Unema, Zapf and Velichkovsky 2001). In a simulated driving study, hazardous events resulted in a sharp increase in fixation duration at 'the cost of the proportion of preattentive fixations' (Velichkovsky, Rothert, Kopf, Dornhöfer and Joos 2002 p. 150). In other words the increased arousal, caused by the sudden appearance of an immediate hazard, shifts visual attention from the ambient (parietal orientating system) to the focal (inferior temporal object-identification system) pole. Since caffeine is documented to increase arousal, it is feasible to suppose that caffeine ingestion will promote the same shift from ambient to focal attention that the perception of danger has been shown to do. If this proves to be the case, this will be another strand of support for the hypothesis that moderate caffeine promotes adaptive behaviours.

1.2.3.7. Caffeine and Object Identification Processes

To ensure safety it is necessary not only to discern and focus on change in the environment, but also to identify the nature of any novelty, that is, to recognize what is, or may be, present in order to assess any potential danger. Object recognition involves a series of complex perceptual processes, which are discussed in more detail in Chapter Five, together with leading theories in the area of object identification. All theories,

however, concede that the ability to maintain shape constancy across different orientations is crucial to object recognition and, in order to maintain shape constancy, mental rotation of imagery is necessary. Accordingly four tests of visuo-spatial ability, all of which require mental imagery to be rotated, are examined for the effects of caffeine. Some tests require simple rotation of an image, such as is presumed to underlie the maintenance of shape constancy across different orientations, whilst others involve more complex operations, such as rotating an image mentally and superimposing it upon the original image. There is no obvious adaptive value to the latter skill, whereas there is adaptive advantage to the former, since it is inferred to underpin object identification. Accordingly, it is hypothesised that caffeine ingestion will improve performance on simple mental rotation tasks whilst having no effect on more complex visuo-spatial tasks.

1.2.3.8. Caffeine's Effect on Categorisation and Speed of Processing

Once an object has been identified, in the sense that its approximate shape and size are known, the next most pressing task, from the perspective of increasing survival chances, is to categorise it: is it a living or non-living thing? If the former, is it prejudicial, helpful or neutral in terms of affecting survival chances? Is it suitable to eat, or is it eying the perceiver with the same thought in mind? Thus the process of abstraction, which constitutes categorisation, although primarily perceptual, is essential to guide action. Hence, categorisation is considered a likely candidate for the facilitative effects of caffeine ingestion, whereas sorting and numerical and verbal processing are not. This is in direct opposition to Lorist's notion of caffeine ingestion affecting input and output processes, discussed briefly above and more fully in Chapter Four.

1.2.3.9. Motivational Shift

The question of what motivates people towards a specific course of action has been much studied, ever since Maslow (1965) presented his theory of a hierarchy of needs. Of the many theories that have followed, Higgins' (2000) motivational self-regulation theory is of particular interest in the present context. Higgins argues that self-regulation involves two separate motivational systems, which he terms promotion focus and prevention focus. The former is activated during situations relating to reward, advancement or accomplishment, whilst the latter is activated in situations relating to punishment, security or responsibility. Since a prevention focus is associated with

maintaining safety and vigilance, and caffeine ingestion has been shown to increase vigilance (Kamimori, Johnson, Thorne and Belenky 2005), it is feasible to suppose that caffeine ingestion may shift regulatory focus away from a promotion focus towards a prevention focus.

Making a decision in a conservative or vigilant manner sustains a prevention focus whereas risky/eager behaviour aimed at maximizing gains sustains a promotion focus. Promotion and prevention orientations have been induced experimentally (Levine, Higgins and Choi 2000) and Cunningham, Raye and Johnson (2004) have identified neural correlates (increased activity in the amygdala, anterior cingulate and extrastriate cortex) associated with the evaluation of promotion and prevention regulatory focus. It has been found that the effects of 'bad' or threatening stimuli are almost universally more powerful than those of 'good' stimuli (Baumeister, Bratslavsky, Finkenauer and Vohs 2001) and thus 'bad' stimuli are the ones that capture attention first and direct action, a finding which is in line with Maslow's (1965) assertion that security (and hence survival) needs must be satisfied before all others. Theoretically, the increased arousal caused by caffeine's ability to block adenosine receptors may be sufficient to shift motivational focus from promotion to prevention, a hypothesis which is tested in Chapter Five and which, should it be supported, will provide another strand of support for the notion of caffeine use as promoting adaptive behaviours.

1.3. Summary

The argument that caffeine ingestion shifts neuronal regulation from a 'safe' state to a 'potentially unsafe' state, that is the theory that moderate caffeine use in healthy adults promotes adaptive behaviours, leads directly to two broad ranges of *testable hypotheses*: firstly, those behaviours which increase the probability of survival in the immediate present will show improvement under caffeine ingestion, whilst those that do not will fail to show benefit under caffeine ingestion; and secondly, an individual whose physiology is presently registering a 'potentially unsafe' state, that is one who is already 'aroused' or 'stressed' before caffeine ingestion, will show no behavioural change after consuming caffeine. In the latter case, caffeine is unable to block adenosine receptors and increase arousal, since adenosine is already present at the receptor sites. Thus, through the perspective of survival enhancement, caffeine's behavioural effects are no longer obscured by the unreliability of covariance with physiological indicators such as

arousal, stress (both of which concepts are problematic in themselves`) or event related potentials (ERPs), enabling sensible and pragmatic decisions about caffeine use to be made.

Caffeine ingestion increases arousal (at the neurotransmitter level by the blocking of adenosine receptors), which is interpreted by the autonomic nervous system as novelty or potential threat (since these are the conditions under which, in a no caffeine situation, arousal is increased). On the one hand, the subjective perception of potential threat instigates a cascade of physiological, psychological and behavioural changes, releasing additional resources with which to counter an objective threat. On the other hand, caffeine ingestion is documented to increase cortical, autonomic and subjective arousal and subsequently to effect a similar cascade of physiological, psychological and behavioural change. When this cascade of effects is considered in detail, as in the following chapter, a pattern emerges: a pattern which shows striking congruence with the behavioural effects of the engagement of different levels of neural regulation, in response to potential stressors, as described in Polyvagal Theory. Caffeine ingestion, through increasing arousal, elicits a shift from the 'safe environment' to the 'potentially unsafe environment' level of neural regulation, together with shifts across a range of behaviours. This shift in neuronal organization promotes adaptive changes in behaviour favouring survival: thus caffeine's behavioural effects become theoretically predictable.

Since there is a substantial body of psychological literature on the effects of stress and threat, it is possible to compare changes that occur under caffeine ingestion with those that occur under the perception of objective threat. If congruence is found, this may provide an explanation for much of the confusion and anomaly presently found in the research data on the effects of caffeine, since it is to be expected that only those behaviours which maximize survival under threat will show the effects of caffeine.

If this proves to be the case, there will be implications for the use of caffeine, particularly amongst children, those prone to anxiety and those whose professions take them regularly into danger. If, as is being argued, moderate caffeine use in healthy adults promotes adaptive behaviour because it shifts behaviour towards survival strategies, which includes defensive behaviours, it might be expected that more false positives would be identified under caffeine ingestion, a situation which may, in some

circumstances, have serious consequences. For example groups such as the police or the armed forces, may be physiologically primed to have a 'light' trigger finger or be more prone to make 'friendly fire' errors of judgement.

A range of experiments testing aspects of threat detection behaviours are reported here. In all cases parametric analysis are used since parametric tests are considered more powerful than the non-parametric equivalents (where such equivalent tests exist) and in all cases parametric assumptions are deemed to have been met. Though there is no evidence of significant differences in caffeine content across the 'skinny lattes' and 'cappuccinos' served in many modern cafes, for the sake of simplicity all experiments used standard freeze-dried instant coffee. As in many published studies of the effects of caffeine, the coffee is administered 'naturalistically', with participants adding sugar and milk to taste, in order to increase the ecological validity of the work. There is no evidence that type or amount of milk or sugar (or more exotic ingredients such as vanilla) added to coffee affect performance. Early caffeine research, which pursued the hypothesis that sugar might be contributing to caffeine's effects on behaviour was not supported. More recently, the debate has been revived in view of the marketing of high glucose, low caffeine energy drinks and Anderson and Horne (2006) have concluded that 'A high sugar content, low caffeine drink does not alleviate sleepiness, but may worsen it' (p299). There are a number of colas, for example Red Bull and Jolt, which include ingredients such as taurine, glucuro lactone and ginseng, which have been shown to affect performance, but these are not examined in this research, since focus of the present thesis is the effects of caffeine administered naturalistically.

Chapter Two

The Caffeine Model: Caffeine Use Elicits Adaptive Behaviours

2.1. The Evolution of Threat Response Strategies

If the contention that moderate caffeine use promotes adaptive behaviours in healthy adults is to be considered valid, the theory needs to be able firstly, to account for all existing, reliably documented effects of caffeine and secondly to generate and support new hypotheses in relation to the behavioural effects of caffeine. Clearly it is not practical to attempt to comment on all (in excess of 30,000) academic papers relating to caffeine here, but to the author's knowledge there is only one reliably documented aspect of caffeine's effects which does not promote survival under perceived threat, and that is the single fact that caffeine is mildly addictive, though this assertion is currently under dispute (Satel 2006).

2.1.1. Fight-or-Flight Behaviours and the Survival Response

It is being argued that the increased arousal caused by caffeine ingestion is interpreted by the nervous system as an indication of potential threat, releasing resources and eliciting behaviours that are appropriate in a threat situation. Since it is being argued that congruence exists between the effects of caffeine ingestion and the physiological changes which occur under the perception of threat, particularly those changes often referred to as fight-or-flight behaviours, a brief summary of some of these changes is given here. The behavioural syndrome referred to as fight-or-flight is part of a wider, species specific, behavioural response to threat, known more accurately as the survival response. Changes under threat perception include increased blood pressure (pumping more fuel and oxygen to the muscles and lungs), increased air supply to the lungs (to feed increased blood supply), release of sugar and increased insulin to the blood ('short distance' fuel supply), increased sustained calcium release to the muscles (greater 'long distance' endurance), release of endorphin from the hypothalamus (blocking the experience of pain), shutdown of the digestive tract (blood diverted to heart and lungs; mouth dries to conserve liquids), increase in cholesterol in the blood (long distance fuel), reduction of sex hormones in both males and females (reduces distraction under threat), increased sweating (to cool the body), measurable through GSR, and all senses enhanced (improved appreciation of potential danger). Similarly, all these changes are also seen after caffeine ingestion, as the research documented below indicates: hence

the new model argues that caffeine's effects are produced through access to additional physiological and psychological resources otherwise available only in times of perceived threat.

2.1.2. Development and Dissolution of Complex Threat Responses

The evolution of behaviours which are elicited by the perception of threat has been driven by the development of the nervous system, as organisms developed strategies for solving ancestral problems. This issue is very relevant to the present thesis and the evolution of the brain and CNS structures, together with regulatory systems, is discussed in detail in the following chapter. In this chapter, specific responses or behavioural strategies known to be elicited by the perception of threat are modelled and compared with behaviours elicited by caffeine use. Although the term 'strategy' is used, this does not imply conscious decision making: one may make a conscious decision to flee or engage in fighting under some circumstances, but when faced with overwhelming threat, the response is involuntary and not subject to conscious appraisal.

In essence, the argument, which is rehearsed more fully below, is that as animals developed from simple to complex organisms, so too did their repertoire of behaviours in response to threat (and other situations) become more complex. This development of behavioural strategies can be seen clearly even within the phylum to which our species belongs: 'older' creatures such as fish (or their descendants) have relatively few strategies when faced with threat, whereas more recently evolved creatures, such as apes, have a broader repertoire of behaviours. What is perhaps less obvious is that 'later animals', such as *Homo sapiens*, carry within them the genetic codes for the behavioural strategies used by creatures which developed very much earlier: such behaviours did not disappear, but rather were overlain by more flexible behaviours. However, as Jackson (1884) shows in his 'principle of dissolution', when a 'recently' evolved animal faces perceived overwhelming threat or terror, its cognition and behaviour revert to that of a less recently evolved animal, that is, those functions which emerged last in evolutionary terms are most fragile and break down first under trauma, behaviour becoming more automatic, less complex and less under voluntary control (Meares 1999). Porges' (1995: 2007) Polyvagal Theory demonstrates how, through changing patterns of neural regulation, these higher cognitive and behavioural functions are, in effect, shut down or bypassed in humans (and other animals) under extreme threat. The precise mechanisms

through which these changes occur are discussed more fully below in a consideration of Polyvagal Theory.

2.1.3. A Hierarchical Model of Threat Responses

Porges' theory of a Hierarchical Response Strategy (1996:2007), that is, that three neural circuits form a phylogenetically-ordered response hierarchy that regulates behaviours that have evolved in response to threat, provides a feasible explanation for the behavioural effects of caffeine ingestion, which is the focus of the present thesis. Within the perspective of Polyvagal Theory, it can be argued that caffeine ingestion affects the mammalian stress response. In other words, caffeine enhances threat monitoring, which includes a variety of perceptual-cognitive changes, enhances the ability to flee from danger whilst increasing endurance and reducing the perception of pain and enhances talking (in humans) and vocalization in other apes, the latter two behaviours being threat diffusion activities. On the other hand, caffeine does not increase the propensity to fight (fighting being originally a reptilian stress response), as for example alcohol does.

Since the concept of physiological stress-arousal is central to theories of perceived threat and stress, as well as being central to the current thesis, Polyvagal Theory is considered in more detail in the following chapter and mentioned only briefly here. According to Polyvagal Theory (Porges 1995; 2007), the autonomic nervous system evolved through three stages, as stress and threat behaviours developed in response to ancestral challenges: together these stages may be seen as the infrastructure for Porges' Hierarchical Model of Threat Response. These stages of development are underpinned by changes and extensions to the vagi, each vagus being a complex of neural pathways originating in the brainstem and providing efferent and afferent pathways throughout the length and breadth of the body. Throughout evolutionary development, from the simplest to the most complex organisms, the primary imperative is survival. Physiological or behavioural characteristics which enhance the probability of survival are perpetuated in subsequent generations, whereas characteristics which do not are suppressed.

As organisms and their behaviour become more complex, so too do the physiological systems which underpin these changes. For example, many simple 'primitive' animals

are stationary, or passive, feeders in a liquid environment, their behaviour supported by the oldest branch of the ANS, the parasympathetic system. This system delivers oxygenated, nutrient rich blood to the brain, heart, lungs and viscera and has limited flexibility. Such animals, when under threat, down regulate the metabolic rate through the unmyelinated visceral vagus, that is, the rate at which food and oxygen are delivered to the system is depressed, resulting in death feigning as a survival tactic, the only option available to such creatures when under threat.

In contrast, animals with increased brain size, and concomitant complex and intelligent behaviour, both of which have obvious survival value, bear the increased costs of an oxygen-hungry system. Although the brain typically is only 2% of total body weight, it uses 20% of available oxygen and 25% of glucose utilization (Poon, Chodzo-Zajko and Tomporowski 2006). Hence a larger and more effective brain is not compatible with the primitive, early, response to threat described above and could only evolve in tandem with the evolution of extensions to the nervous system. The development of the sympathetic nervous system, which enables increased metabolic output but inhibits the visceral vagus, permits mobilization behaviours, such as fight-or-flight, whilst the mammalian myelinated vagus allows cardiac and bronchial output to be rapidly regulated in response to changes in the environment. In addition, the fine regulation of the heart and bronchi promote calm states in which self-soothing is fostered. These developments in physiology and neural regulation are summarized as follows:

- At Stage 1 a primitive, unmyelinated, visceral vagus developed, which supports digestion and response to threat by depressing metabolic activity, that is, the ‘freezing response’.
- At Stage 2 the visceral vagus is inhibited by the function of the sympathetic-adrenal nervous system, permitting increased metabolic output and supporting ‘fight-or-flight’ behaviours.
- At Stage 3 the mammalian myelinated vagus, which is able to respond rapidly to changes in the environment through regulating cardiac output, develops, together with cranial nerves which regulate facial expression and vocalization, forming in ‘later developing’ mammals a ‘social nervous system’.

At the present level of evolution, when faced with a threat to survival, animals which have direct links to the evolutionarily oldest creatures, such as some fish, rely on death

feigning to escape threat, amphibians and reptiles have the added strategy of fighting, mammals are able to utilise extended flight and apes to engage in negotiation and stress diffusion. This latter strategy has developed further to one of ‘tend and befriend’ (Taylor, Klein, Lewis, Gruenewald, Gurung and Updegraff 2000), which is most obviously seen in adult female apes and in the ‘soothing’ behaviours of many female animals after young which have been taken from the mother are returned to her, and is underpinned by the ‘bonding’ hormone, oxytocin.

However, as Jackson (1884) has demonstrated, under extreme stress more recently evolved strategies for dealing with threat break down: in humans negotiation gives way to fight-or-flight (fuelled by adrenaline) and fight-or-flight gives way to trauma paralysis or psychosis-induced catatonia (a neurogenic process in which blood is sent away from the brain to the abdomen, the heart slows and most voluntary processes shut down).

Although the notion of human males being primed for negotiation and flight, rather than fight, is clearly at odds with the machismo male portrayed in popular culture, the potential cost of the alternative is maladaptive in the extreme. Fighting to the death (as rather few animals do), severely reduces a male’s chances of further reproductive opportunities, whereas fleeing is far less punitive. Young human males play fight and adolescents join competing gangs (though research shows that gangs of adolescents posture and threaten, whilst avoiding actual conflict most of the time: Hazlehurst and Hazlehurst 1998), whereas adult human males fight rarely, unless fuelled by alcohol, other drugs or suffering from traumatic brain damage (Tateno, Jorge, and Robinson 2003). Only in the exceptional circumstances of severe threat to a male’s resources (for example, food, shelter, breeding partner or reputation) does a normal male engage in seriously damaging fighting: if this were not the case, the time and money that is spent, and has always been spent, on preparing men for war would be needed, instead, to prepare them for civilian living.

2.1.4. An Evolutionary Perspective on the Threat Response

The following outline, which is based on Porges’ (1997) Hierarchical Response Strategy model and Polyvagal Theory (2007), details some of the increasingly complex behaviours that arose over time in response to threat, in tandem with more complex

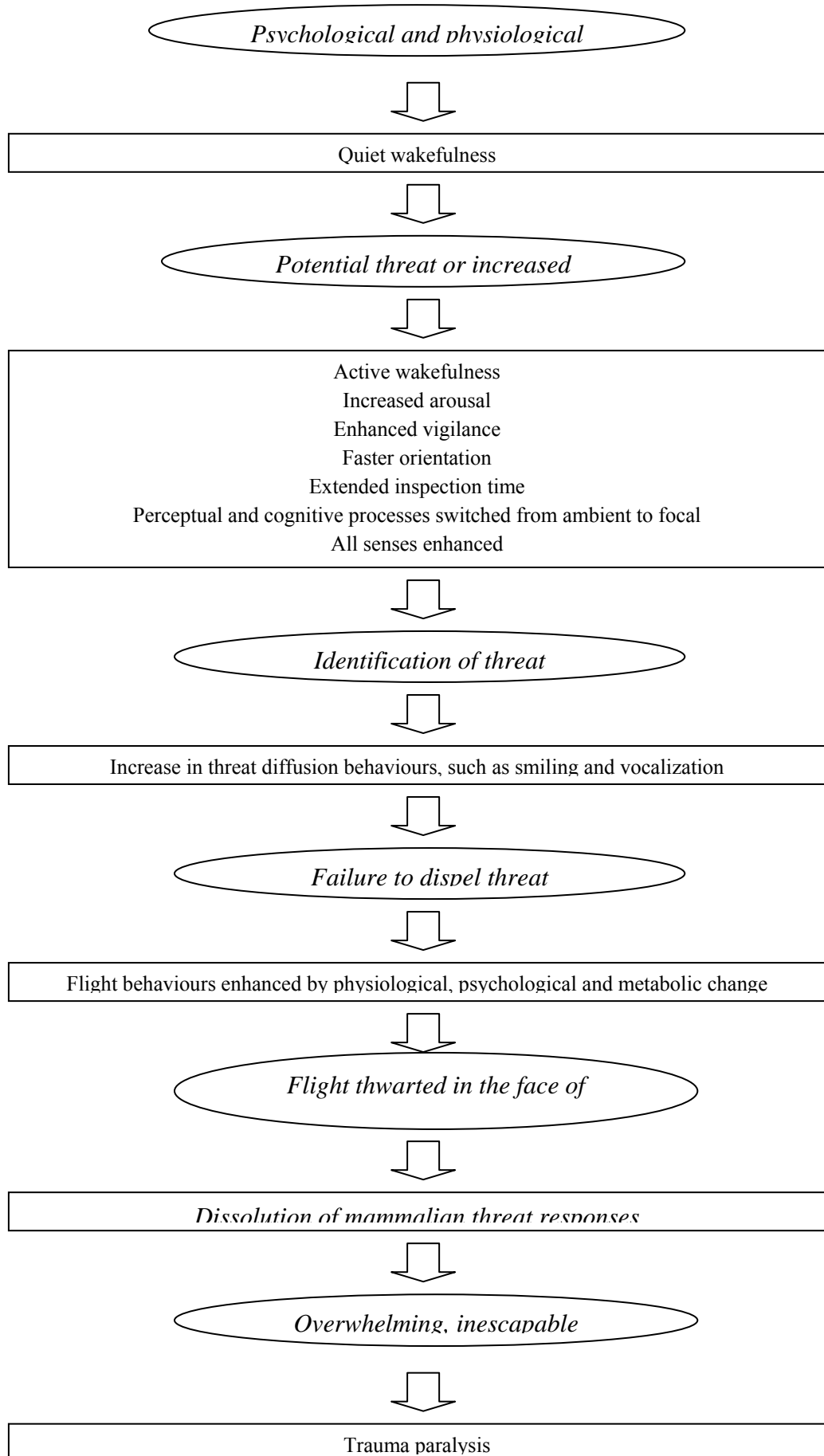
physiology. Behaviours which developed amongst evolutionary older or 'earlier' animals may be elicited in humans by trauma, just as Jackson's theory of dissolution predicts. As mentioned above, for some fish with particularly ancient lineages, death-feigning is the only strategy available to them under extreme threat, but animals with a broader range of possible responses to threat, such as rats, rabbits or deer also 'freeze' when overwhelmed with a sense of danger (for example, being faced by a genuine predator or car headlights), despite their broader repertoire of behaviours. In humans the response known in phylogenetically older fishes as death-feigning is usually termed 'trauma paralysis' and offers an explanation for the often reported experiences of wanting to scream, when under threat, but being unable to do so, or being able to defend oneself.

As animals developed over evolutionary time, Polyvagal Theory argues that additional behavioural responses to threat accompanied the increased complexity of the nervous system in classes of later developing animals, such that a cold-blooded reptile's primary response is to fight, (its physiology dictating little capacity to flee), whereas warm-blooded mammals have as their primary strategy flight, and apes, being the most recently evolved animals, have additional stress diffusing behaviours of extensive facial and complex vocal expression.

Hence, evidence to support the present thesis, that caffeine use elicits adaptive behaviours, may be found in demonstrating that caffeine facilitates threat monitoring behaviours, the ability to flee and threat diffusion behaviours.

In addition to the three main classes of response to threat, that is, death-feigning, fighting and fleeing, there are additional behaviours seen under stress-arousal, for example, species specific posturing, which in many situations allows a challenge to be decided without the very real costs of fighting. Posturing, however, is only possible when the threat is not immediately overwhelming. Additionally, many animals, including humans, will fight to preserve or obtain important resources such as food, shelter, mates or reputation. Despite these caveats, the primal response to overwhelming threat in humans is not to fight: it is to attempt stress diffusion negotiations and, if that fails, to flee.

Figure 2-1: States of Readiness: Gross Behavioural Change Under Threat Perception



The costs of attempting to fight an overwhelming threat are simply too great to engage. The different stress responses and behavioural strategies are orchestrated, according to Polyvagal Theory, through the vagus nerves: only mammals benefit from the ‘smart vagus’, and only apes from the most recent development, enabling stress diffusion ‘negotiations’ through complex vocalization.

Figure 2-1 illustrates the above in diagrammatic form. However, the description of behaviours is very general, and there are very many fewer listed than actually change under perception of threat: our present state of knowledge appears to be far from sufficient to allow a full consideration of the complexities of the process, enabling only an examination of gross changes in, for example, behaviour.

This model illustrates the range of behavioural strategies available to *Homo sapiens* (and to other animals, depending on their evolutionary position and concomitant differing levels of complexity). Organisms use the most highly evolved response, or ‘circuit’ available to them, but if that should be overwhelmed and fail they then use an older system: should that also fail, behaviour reverts to that governed by the oldest vagal ‘shutdown’ system. Underpinning the above model is Porges’ hierarchical response to challenge model, which incorporates the ‘Theory of the Evolution and Dissolution of the Nervous System,’ first put forward by Jackson in 1884. This provides a feasible rationale for the fact that, just as a rabbit will freeze in a car’s headlights, so too may *Homo sapiens* become frozen with terror.

It is argued that caffeine ingestion elicits mammalian mobilization behaviours of higher levels of vigilance, ‘flight’ though not ‘fight,’ together with stress diffusion behaviours and increased vocalizations. The literature suggests these effects are achieved through caffeine’s effect on adenosine and muscarinic receptors, though the present model and analysis relies on behavioural measures and observations.

2.2. The Model: Caffeine Use Elicits Adaptive Behaviours

The notion that caffeine ingestion elicits elements of the mammalian threat response underpins the present thesis and has the potential to clarify much of the confusion presently surrounding which aspects of cognition and behaviour are affected by caffeine. If the behaviour under consideration contributes to the speedy perception and

identification of close but novel stimuli, which are potentially threatening until proven otherwise, it is highly probable that caffeine will have an effect, that is, the behavioural effects of caffeine are **specific** to particular processes which underpin threat strategies. Hence the model has predictive value and is of pragmatic use in the everyday world. In a laboratory situation, it is to be expected that response times to images flashed onto a screen will be shorter when the participant is under caffeine ingestion (or alternatively, under threat) than when not, and that response times to local or foveal images will be faster than to global or ambient stimuli. Additionally, cognitive processes which enable identification of stimuli, such as object recognition or categorization, are also predicted to be enhanced under caffeine ingestion, whereas other cognitive processes, for example simple arithmetic, reading, or letter identification, are not. Also the model predicts that verbal fluency will be enhanced by caffeine ingestion, whereas verbal processing will not be.

Outside the laboratory, it is possible to predict from the model which kinds of behaviours will be affected by caffeine ingestion. If a behaviour contributes to fast escape, for example, putting distance between the threat and the perceiver (as, for instance, in running or cross-country skiing), caffeine will likely improve performance, whereas sports which rely on strength or power, such as weight lifting, boxing or wrestling, are predicted not to be affected by caffeine ingestion. In addition, it is also possible to predict that when a situation or task is stressful, such as when participants are anxious, or carrying out an inherently stressful task, such as the Stroop task (which causes cognitive conflict), caffeine will have no effect. In such cases the stress or challenge of the situation causes adenosine to be released so the adenosine receptor sites, which caffeine would normally fill, are already blocked. There is therefore no further increase in arousal and hence no signal to release additional resources. The empirical studies reported in following chapters are designed to test these predictions.

2.2.1. Congruence: Perceptual Changes Elicited by Both Caffeine Ingestion and the Perception of Threat

Evidence from peer reviewed research data of the congruence between behaviours elicited under the perception of threat and under caffeine ingestion is freely available. The following literature review is selective, as all such reviews must be. It is certainly true that the research findings cited below have been chosen for their ability to clarify

the arguments contained within the present thesis, but it is not the case that any reliable findings of caffeine's effects have been ignored because they constitute a problem for the theory: quite simply, the author has so far been unable to find reliably documented effects that would pose a problem for the theory. However, there are a number of tasks, especially in the area of cognition, on which the effects of caffeine ingestion have been tested, but the effects of threat or severe stressors have not: the caffeine data are included for completeness. For example, an effect of caffeine ingestion on memory is recorded (Herz 1999) but, understandably, there appear to be no laboratory studies documented of memory under an acute threat/fight-or-flight state. Clearly there are sound ethical and logistic reasons for this gap in the data.

2.2.2. Evidence that Caffeine Increases Arousal

When threat is a pervasive feature of the environment, arousal is critical in identifying and defending against it. However, 'arousal', in the broad, psychological sense, is to some extent a convenient and useful fiction. While the concept is pragmatically useful in organizing behavioural data, since the reality of a constantly changing, complex, pattern of inhibition and excitation produced by very many neurotransmitters, neuromodulators and hormones at multiple sites, producing many, differing, states of physiological and cognitive excitation-inhibition, is presently beyond our ability to differentiate, measure or interpret, the construct is far from precise. Although there is no doubt that caffeine's antagonistic effect on adenosine suppresses noradrenaline, dopamine and acetylcholine and increases cerebral glucose utilisation, the complexity of interactions of these and other neurotransmitters and hormones means that caffeine's effects on arousal cannot easily be localised to any particular brain system (Yoshimura 2005) An example of the kind of problem involved is shown when psychophysiological measures are taken after the stimulants caffeine, nicotine or amphetamine have been administered. Increased physiological arousal is shown in all cases, yet, since nicotine is a cholinergic agonist and amphetamine affects the dopamine pathway (Warburton 1998), whilst caffeine affects the muscarinic receptors, it is clear that at least three different neurotransmitter systems are being utilised. 'Arousal' is a slippery, if necessary, concept when considering the effects of a stimulant: hence the term 'stress-arousal' is preferred in this thesis, whilst conceding that the 'arousal' half of this term still creates difficulties.

According to Gordon (2006),

Arousal refers to a comprehensive change in body chemistry, brain and psychological functioning that focuses resources on the immediate threat ...colloquially referred to as 'adrenaline pumping' (p. 14)

and is elicited in circumstances of change, novelty, uncertainty and conflict, where action must be improvised. This is a coherent and appealing definition, but still lacks precision and concreteness. For example, many studies attest to increased physiological arousal following caffeine ingestion. However, it is not the case that increases in, for instance, electrocortical arousal or EEG are necessarily associated with increases in subjective stress or arousal (Fechir, Schlereth, Purat, Kritzman, Geber, Eberle, Gamer and Birklein 2008), nor is it the case that such physiological changes predict behavioural change, as witnessed by the extant conflict and ambiguity in research data on performance after caffeine ingestion. Although there is a clear consensus that caffeine increases physiological arousal, in some circumstances this increased arousal is translated into behavioural change, whereas in others it is not. For example, the critical flicker fusion threshold (CFFT) is considered to be a valid and reliable pharmacosensitive and psychophysical measure, which reflects CNS arousal (Curran 1990), yet five out of seven studies failed to find any effects of caffeine on CFFT. However, a later study using CFFT (Corr, Pickering and Gray 1995) found an interaction between caffeine and baseline sociability, which is what the present thesis would predict.

The problematic nature of the concept of 'arousal,' which has been referred to as the 'albatross of psychophysiology' (Matthews, Davies, Westerman and Stammers 2000, p.166), has long been noted and shows no immediate signs of resolution. For present purposes, Faw's (2006) description and analysis of a continuously active brain (structure and process) and Porges' (2003) description and analysis of continuously changing patterns of neural regulation are accepted as probably the best explanations currently available of the mechanics of 'arousal'. During life there is always brain activity and this brain activity may be considered at the level of anatomical structures or physiological networks or both, differing levels of activity in different structures being interpreted and described as different states of consciousness, or cortical arousal, from

rapid eye movement (REM), through states of ‘quiet wakefulness’ (Jones 1998), such as restfulness, trance and meditation, to primed-for-action ‘active wakefulness’ (Speigle and Speigle 2004). Hence, as Faw argues, the traditional term ‘arousal’, which implies homogeneous, whole cortex activation is unhelpful and, if valid, would result in ‘functional mayhem’ (p. 201). Researchers on the effects of caffeine (and other stimulants) have been faced with the problem that the same stimulant, administered at the same dose, does not necessarily produce the same effects across a sample, nor indeed the same effect in the same individual on different occasions. It is only when the complexity of the individual’s state of mind (and pattern of cortical arousal) is accepted as an additional variable in the experimental paradigm that these anomalies become amenable to potential explanation.

Despite these potential difficulties, the reported effect of caffeine increasing general cortical arousal is sufficiently robust to be well documented (for example, Coren 2002; Gottselig, Adam, Retey, Khatami, Achermann and Landolt 2006). Many studies of caffeine’s effects on specific cognitive tasks also refer to increased arousal, if not specifically to increased cortical arousal. For example, a study of the effect of caffeine on the Stroop task used change in event related potentials as a measure of arousal (Deslandes, Veiga, Cagy, Pieda, Pompeu and Ribero 2004), whereas skin conductance level, heart rate, systolic and diastolic blood pressure and respiration rate were used as a measure of caffeine’s arousing effects by Barry, Rushby, Wallace, Clarke, Johnstone and Zlojutro (2005). It is concluded that the premise that caffeine increases stress-arousal is supported by a variety of psychophysiological and behavioural measures, that is, caffeine ingestion precipitates a change from a physiological state of neuronal readiness appropriate to an environment perceived as safe, to a state of ‘get ready, get set’ for action.

2.2.3. Evidence that Caffeine Improves Vigilance

In maintaining safety, the first level of defence is vigilance, that is, a constant monitoring of surroundings against any change to a presently safe environment. Even when ‘at ease’, to use Faw’s preferred term, or in a state of basic cortical arousal, cortical cells are primed to fire, so that they are readily activated by the impingement of appropriate novel stimuli, brainstem projections to the acetylcholine cells in the basal forebrain being considered, according to Dringenberg and Vanderwolf (1998), the

means through which incoming stimuli, or perceived changes to the environment, activate arousal, motor control and salience detecting systems. Since vigilance is the first line of defence against potential threat, in order to support the hypothesis that moderate caffeine use elicits adaptive behaviours and enhances survival chances, it is necessary to show that vigilance performance is enhanced by caffeine ingestion.

In fact there have been in excess of a hundred refereed papers on the beneficial effects of caffeine on vigilance performance and/or sustained attention published in just the last twenty years (for example, Childs and de Wit 2006). These papers cover a wide range of laboratory and real world research, examining applications such as, amongst others, counteracting sleep loss (Kushida 2006), supporting performance during demanding night time flying (Doan, Hickey, Lieberman and Fischer 2006) or night time special forces missions (McLellan, Kamimori, Voss, Bell, Cole and Johnson 2005), facilitating shift work (Souza, Paiva, Reimao 2005), compensating for age related cognitive deficits (Rees, Allen and Lader 1999) and moderating spatial deficits in attention deficit hyperactivity disorder or ADHD (Prediger, Pamplona, Fernandes and Takahashi 2005). In addition, the studies examine a wide range of cognitive tasks, though the emphasis has been on visual and auditory vigilance performance. Such studies have been reported for over fifty years: for example, amongst many early studies of visual and auditory vigilance, Mackworth (1950) using the Mackworth Clock, Bakan (1959) using the Bakan or Rapid Information Processing task, Smith, Rusted, Eaton-Williams, Savory and Leatherwood (1990) again using versions of the Bakan task, Fine, Korbrick, Lieberman, Marlowe, Riley and Tharion (1994) and Wilkinson (1968) using the Auditory Vigilance Task have all documented caffeine's beneficial effects on vigilance. More sophisticated paradigms in which cortisol levels are monitored continue to show the beneficial effects of caffeine on vigilance performance (e.g. Gilbert, Dibb, Plath and Hiyane, 2000).

Snel and Lorist (1998) report that 'studies examining caffeine's effects on vigilance performance while using a diversity of visual and auditory vigilance tasks, found that caffeine, to a more or lesser extent, improved the overall level of vigilance' (p. 178). Of particular interest to the present thesis is the question of whether caffeine increases the ratio of false alarms to hits as has been reported by Swift and Tiplady (1988), indicating a shift in the participant's response criterion, which it is suggested here would indicate

the engagement of the body's survival enhancement system. Our distant ancestors lived in a world where predators, both human and animal, were common place: in such a world the cost of failing to react to a potential threat may have been death, whereas the cost of reacting unnecessarily to a potential, if unfounded, threat was negligible.

2.2.4. Caffeine Ingestion Affects the Orienting Response

If, as is being argued, caffeine ingestion shifts neuronal and behavioural readiness towards the perception of potential threat, it is plausible to expect that caffeine use reduces the time taken to orientate to a novel stimulus, that is, that the orienting reflex is faster, that the inspection time is extended and that habituation to a novel stimulus, which may be threatening, is delayed. This is in fact the case with respect to visual and stimuli (Bhattacharya, Satyan and Chakrabarti 1997). The function of speedier orientation is self evident, that is, the faster a threat is perceived, the greater the probability of survival, but the reason for the extended inspection time and delayed habituation is less obvious. The most likely explanation would seem to be that the longer inspection time is needed for identification or categorization of the stimulus as non-threatening/threatening, since an error at this stage might be fatal.

Categorization is usually thought of as the process through which knowledge is organised and hence the building block of higher cognitive processes, but it seems clear that, under the stress of increased arousal from perceived threat, categorization has, in addition, the potential to be life-saving. Since virtually all animals, including those with relatively underdeveloped cognition, are capable of this categorisation process (notably of the 'is X food for me, or am I food for X?' variety), it is likely that such processes are almost as old as animal life itself.

The delay to habituation may be another fail-safe mechanism: increased arousal indicates potential threat, so checking several times (before habituation) is likely to be adaptive. This interpretation of the data is supported by an experiment, carried out by Nummenmaa, Hyona and Calvo (2006), not involving caffeine, in which emotionally arousing scenes, were fixated faster and gazed at longer, as opposed to neutral targets. Since it has been shown that caffeine similarly disrupts habituation (Schicatano and Blumenthal 1995), it is probable that the underlying mechanism is again increased arousal.

2.2.5. Caffeine Ingestion and the Acoustic Startle Reflex

The startle (or Moro) reflex in infants involves the infant suddenly bringing arms and legs in towards the body, in response (usually) to either a loud noise or the infant being tipped suddenly (as though falling). For many years it was assumed that this behaviour derived from the time when the young of our ape ‘ancestors’ clung to the adult, whilst the adult swung through trees or ran across savannah, the infant clinging tightly to facilitate survival. This interpretation of the roots of the behaviour may well have merit, and certainly cannot be disproved, although it raises the question of why, as adults, we continue to flinch when we hear an unexpected noise. More recent research offers an alternative interpretation for the acoustic startle reflex. Yeomans, Li, Scott and Frankland (2002) show that the most sensitive areas of the brain to the startle reflex are the trigeminal nuclei, which relay tactile information from the brain. When information from the auditory and vestibular pathways arrives within 20 milliseconds of the tactile data, the startle response is elicited. As a result, Yeomans argues that the startle reflex evolved to protect the body, particularly the head, against blows.

Within the perspective of the present thesis, either interpretation leads to the hypothesis that caffeine ingestion will affect habituation to the startle reflex, and prior research demonstrates that this is the case (Swerdlow, Eastvold, Gerbranda, Uyan, Hartman, Doan and Auerbach 2000). In other words, the potential protective mechanism of the startle reflex is extended by the presence of caffeine in the body.

2.3. Caffeine and the Survival Response

The survival response, though universally acknowledged, is too complex for a full understanding to be presently available. The responses to imminent threat appear to fall into five natural categories: death feigning or freezing; flight; threat diffusion (amongst primates); posturing; and fighting. Of these behaviours the most studied, particularly in relation to humans, is the subset of changes sometimes called the ‘fight-or-flight’ syndrome, a cascade of physiological and psychological changes elicited by acute or chronic threats to survival. Polyvagal Theory and the Evolutionary Model of Stress Response suggest that ‘fight-or-flight’ may not be the most appropriate way in which to describe the mammalian response to extreme threat, since the primary response is flight, rather than fight together with, in apes, the recently evolved strategies of stress diffusion

and 'discussion'. However, the term 'fight-or-flight' is so thoroughly embedded within the literature on stress, threat and physiology that its use cannot reasonably be avoided at the present time. In order to support the present thesis, that caffeine ingestion creates an environment in which the body has shifted to a state of increased threat perception, evidence is needed that the same physiological and psychological changes observed in the 'flight' element of the 'fight-or-flight' syndrome are evident after caffeine ingestion.

A brief review of the remarkable concordance between the physiological and psychological changes which facilitate fight-or-flight responses, together with the equivalent caffeine-induced physiological and psychological changes, is therefore seen as appropriate. During the fight-or-flight response, the heartbeat quickens: a racing heartbeat pumps more blood to the muscles and lungs, enabling faster transportation of fuel and oxygen around the body, which is beneficial to escape behaviour. Caffeine also quickens the heartbeat and increases blood pressure. (Nurminen, Nittynen, Korpela and Napaatalo 1999).

In the fight-or-flight response, bronchioles dilate and breathing deepens: this provides more oxygen to feed the increased supply of blood coming into the lungs, which again is beneficial to escape behaviour. Caffeine also dilates bronchioles and is widely used to treat infant apnea (Bancalari 2006) and asthma (Taylor, Smith, Cowan, Herbison and Taylor 2004).

In addition, during the fight-or-flight response, there is a shutdown of the digestive tract: blood is diverted from the digestive system to muscles, heart and lungs for increased physical effort and endurance, the mouth goes dry (conserving liquid) and bladder and bowel empty prior to action. Adenosine inhibits physiological activity generally and has antidiuretic and lipid inhibition properties (Kenny, Carlson, McGuigan and Sheppard 2000). Caffeine's ability to create a dry mouth and necessitate a visit to the bathroom is well supported anecdotally.

During the fight-or-flight response endorphin is released from the hypothalamus: in an attack or escape situation, the pain killing effects of endorphin being beneficial to survival chances. Caffeine is a component of many analgesics because it is documented to improve their pain killing effect and reduce inflammation. Pageler, Diener,

Pfaffenrath and Hubertus (2009) report doses of analgesic were perceived to achieve very much higher levels of pain relief when caffeine was co-administered. This effect is presumably due to the activation of the endogenous opioid system, frequently observed during stress (Sudakov, Medvedeva, Rusakova and Figurina 2003) and the engagement of the muscarinic system, which caffeine is known to affect (Lorenza, Colzato, Fagioli, Erasmus and Hommel 2005).

During the fight-or-flight response, there is an increase in cholesterol in the blood, derived from the liver, as there is when caffeine is ingested (van Dam 2008). Since the stomach has shut down, the increase in cholesterol provides necessary fuel for the muscles. In addition, there are increased clotting factors in the blood (Gyntelberg, Hein, Suadicano and Sorensen 1995) offering more capacity to carry oxygen, fight infection and stop bleeding from wounds; this is also the case with caffeine ingestion.

In the fight-or-flight response, sweating increases in order to cool underlying, overheated muscles; under caffeine ingestion sweating increases, as measured by electrodermal activity (EDA). In addition, sugar is released into the bloodstream, together with an increase in insulin, in both the fight-or-flight response and when caffeine is ingested.

However, this massive diversion of resources from normal functioning to functioning under perceived threat does not affect behaviour across the board: some physical activities benefit, under both caffeine ingestion and threat perception, whilst others do not. This is most clearly seen when caffeine's effects on sports performance are considered.

2.3.1. Caffeine's Effects on Physical Performance and Endurance

The ergogenic effects of caffeine are well known, to the extent that in 1984 caffeine was declared a banned substance by the International Olympic Committee, consumption being limited to normal 'social' use, such that urinary caffeine concentration does not exceed 12 µg/ml and in 1988 an athlete was disqualified for exceeding this limit. In the area of sports performance, as in all others, caffeine's effects are selective. Specifically, caffeine increases endurance in sports which cover distance (e.g. middle and distance running, swimming, rowing, skiing) and stop and go events (e.g. team and racquet

sports) but does not improve performance on sports which involve strength and power (Burke 2008). That is, physical endurance, but not power, is enhanced by caffeine ingestion. It is possible to speculate that, under threat, improvements in speed and endurance are more likely to improve survival chances than improvements to muscle strength *per se*.

McLellan, Bell and Kamimori (2004) examined caffeine's effects on physically demanding tasks including a two-hour forced march, piling sandbags and a treadmill run to exhaustion when participants had been deprived of sleep for 28 hours, concluding that caffeine maintained performance to levels comparable to non-sleep deprived participants. A study by Tarnopolsky and Cupido (2000) offers an explanation for this effect. Athletes were given, double-blind, 600mg of caffeine or placebo before being tested to exhaustion on exercise bikes and then having their leg muscles stimulated electrically. Those athletes with 'caffeine laden' muscles showed a 25% greater response than the placebo group. It appears that caffeine enhances the release of calcium from the sarcoplasmic reticulum, the network of tubules within muscle cells which acts as a holding tank for calcium. After prolonged exercise the calcium release mechanism normally becomes lethargic, but caffeine appears to free it up to continue working. This work demonstrates convincingly that caffeine is not merely a CNS stimulant but also a muscle stimulant, for particular kinds of muscles under specific conditions, such as meeting the demand for endurance in distance- covering activities, for example running, cycling and skiing, and presumably, escaping a predator.

2.3.2. Caffeine's Effects on Motor Co-ordination

Studies of the effect of caffeine ingestion on motor performance have tended to focus either on fine muscular co-ordination, as in hand steadiness, or on graphonomics, the relationship between planning and generation of fine motor tasks. As in so many other areas, the results of studies on motor co-ordination are contradictory, some early research (e.g. Jacobson and Thurman-Lacey 1992) finding that caffeine ingestion impairs hand steadiness and others (e.g. Gillingham, Keefe and Tikuisis 2004) finding that on the contrary, caffeine improves performance.

Explanations in the literature (e.g. Snel and Lorist 1998) for this contradiction tend to focus on experimental variables such as dose of caffeine, participants' habitual caffeine

use and differences in the research protocols. Although these explanations are valid, within the present thesis an additional possibility is evident: as Carlson and Chemtob (2000) note,

A problem for the survival system is that it must be both inhibitory as well as activating in effect. People ... have difficulties with the regulation of activation and inhibition, for example, shifting into 'survival mode' at slight provocations and becoming highly activated (p 268).

Within the present argument, 'highly activated' may well equate to the behavioural strategy of flight, which the circumstances of an experiment in a psychology laboratory, make inappropriate. Hence the 'activating' effect of caffeine ingestion or perceived stress, in which the muscles are primed for flight by an increased flow of calcium (Bhaskar, Subbanna, Arasan, Rajapathy, Rao and Subramani 2008) is in direct opposition to the requirements of the situation and an inability to balance the activating and inhibitory effects may well result in tremor.

2.3.3. Caffeine's Effects on Reaction Time

Reaction time is a measure of caffeine's effects on performance that has been widely tested across different tasks and different experimental paradigms. For example, Smith (1998) used simple reaction time, five-choice serial response and vigilance tasks to demonstrate the effects of different doses of caffeine and to demonstrate, with caffeine naïve participants, that the effects were not due to prior withdrawal from habitual caffeine use. Van der Stelt and Snel (1998), in their comprehensive review, report many experimental situations in which caffeine has decreased reaction time, but also a substantial number in which it did not: the authors attribute this discrepancy to moderator and mediator variables within the subject, within the task and within the experimental situation (examples of the latter include time of day, noise, dose of caffeine and length of period between caffeine administration and testing). They state their conclusion as 'Two tentative general mechanisms ... an indirect, non-specific 'alertness', 'arousal' or 'processing resources' factor [and] a direct and more specific, cognitive, or 'perceptual-motor' speed or efficiency factor' (p. 182). These conclusions do not, arguably, detract from the present thesis, but neither do they hold any great explanatory power.

2.3.4. Caffeine's Effects on Aggression

An area where caffeine's effects are under-researched is that of the effect on aggression. There are several early reports of decreased aggression and hostility in psychiatric patients when caffeine has been made unavailable to them (e.g. Edelstein, Keaton-Brasted and Burg 1984), suggesting that caffeine, when consumed, was contributing to the inpatients' aggressive behaviour, though these do not appear to have been replicated recently. Laboratory studies on normals indicate that caffeine, whilst exacerbating anxiety, reduces aggression. Children suffering from attention deficit disorder showed significant reductions in aggression, impulsivity and hyperactivity when caffeine was added to their regime of stimulant drugs (Leon 2000). However, in comparative studies, such as that reported by Wilson, Nugent, Baltes, Tokunaga, Canic, Young, Bellinger, Delac, Golston and Hendershort (2000), it is reported that 'in all (non-human) species studied' high doses of caffeine reduce aggression but low and moderate doses of caffeine increase aggressive behaviour. The details of procedure in these comparative studies vary greatly, particularly in the extent to which the animals were stressed before caffeine ingestion, so it is difficult to offer anything other than speculation. However, within the framework of the present thesis and the hierarchical response to stress contained within Polyvagal Theory, it is possible to suggest that the low doses of caffeine shifted animals into the fight-or-flight response, and that, since flight was impossible in the laboratory experiments, the phylogenetically older response of fighting was inevitable, and further that the high doses of caffeine pushed them towards immobilization behaviours.

As far as aggression in normal humans is concerned, Alexander (2004), in a study of 114 males and females, from 17 to 79 years old, reports that a caffeine intake of greater than one serving per day correlated with increased self-reported aggressive driving habits, typical of road rage, though this effect applied only to males. Since there is evidence that 'the correlation between testosterone and attack behaviors in humans is real' (Kalat 1998 p. 333), if relatively weak, the gender difference is not entirely surprising. The data suggest that caffeine is not a causal agent in aggression *per se*, but may, in some situations, especially those of restriction or incarceration, exacerbate stress and the perception of threat, which may lead to aggressive action, especially in males.

2.3.5. Caffeine's Effects on Anxiety

Mild anxiety, in the absence of caffeine, promotes reasonably cautious behaviour. However, as has been argued above, in raising the level of arousal, caffeine changes perception of the environment from safe to potentially unsafe, so the degree of potential threat experienced will depend on any additional stressors, internal or external. Accordingly, it might be predicted from Polyvagal Theory that individuals who already suffer from anxiety would report greater anxiety after caffeine ingestion and this is what the research record shows. Several studies have reported positive correlations between long term caffeine use and increased anxiety in patients who suffer from a range of anxiety disorders, though this effect was not found in normals. Boulenger, Uhde, Wolff and Post (1984) report that patients with anxiety disorders voluntarily discontinued caffeine use because of unpleasant 'side effects', though this finding does not appear to have been replicated. Rihs, Muller, and Bauman (1996) argue that caffeine consumption for patients with psychotic disorders should be routinely monitored, since these patients are at highest risk of excessive caffeine consumption.

A study of 290 medical students in Japan (Mino, Yasuda, Fujimura and Ohara 1990) indicates gender differences on the effects of caffeine in humans. Among males, caffeine consumption was significantly positively related to symptoms of anxiety, but there was no relationship between caffeine consumption and depressive symptoms. Amongst females, however, no relationship was found between caffeine consumption and anxiety, but an inverse relationship between caffeine consumption and depression was found. The apparent protective effects of caffeine in women against depression are further supported by a prospective study of coffee drinking and suicide by Kawachi, Willett, Colditz, Stampfer and Speizer (1996) who followed a cohort of female nurses over ten years, concluding that the fifty-six suicides found in 832,704 person-years of observation represented a strong inverse relationship between coffee consumption and suicide.

These gender effects can be accommodated through the perspective of Polyvagal Theory: it would be predicted that the increased arousal and shift in patterns of neural regulation found after caffeine ingestion would be uncomfortable to those whose levels of arousal were already comparatively high. The significant difference in levels of

testosterone between males and females may well play a part in this, since higher levels of testosterone are reported to decrease aversive behaviour towards threatening stimuli and facilitate approach to dominance challenges (Wirth, Welsh and Shultheiss 2006), any challenge inevitably precipitating a sense of increased anxiety. However, the increased arousal caused by caffeine ingestion would benefit females, whose levels of arousal had previously been depressed compared with males.

Some authors have argued that patients with anxiety disorders have an exaggerated sensitivity to caffeine (Lee, Cameron and Greden 1985), though it is not clear whether such patients experience caffeine's effects more strongly than non-patients or are just more likely to attribute these effects to anxiety. The picture is clearer when considering the research on caffeine and patients suffering from panic disorder, who clearly do have an especially intense response to caffeine. Since caffeine suppresses the adenosine receptor system, it has been suggested that individuals who exhibit panic disorder have increased numbers of adenosine receptors, or receptors that have an unusually high affinity for caffeine (Apfeldorf and Shear 1993). Overall, it would seem that patients suffering from a range of anxiety disorders perceive the environment as generally more threatening than normals do, and that the ingestion of caffeine exacerbates this effect.

2.3.6. Caffeine's Effects on Subjective Mood

Counter-intuitively, though in line with what would be predicted from the present thesis, the anecdotally familiar notion that caffeine ingestion leads to a more positive mood state, is difficult to substantiate from the research literature, although there is at least a partial consensus that caffeine increases subjective alertness. On the one hand, Warburton (1995) reports increases in clearheadedness, happiness, and calmness and decreases in tension after low doses of caffeine to 18 healthy adults. On the other hand, Swift and Tiplady (1988), in a study of young (18-37 years old) and elderly (65-75 years old) participants, report age differences in the effects of caffeine on mood, stating that younger participants reported feeling more alert, calmer and steadier on caffeine, whereas older participants did not report these subjective changes, although objective measures of improved reaction time and attention are reported for both groups. Herz (1999), however, reports no mood change, other than increased alertness, in a laboratory experiment. This suggests that caffeine's effects on behaviours such as reaction time, are elicited at a level below conscious awareness of a change of mood state.

2.3.7. The Effect of Caffeine Ingestion on Cognitive Performance

Although the fight-or-flight syndrome describes physical behaviour, faster feet without faster thinking would be unlikely to confer much advantage. There is a substantial literature on the negative effects of chronic 'stress' on cognitive performance (e.g. Kenny, Carlson, McGuigan and Sheppard 2000; Ljunberg and Neely 2007), but much less on the anecdotally familiar notion of quick thinking 'on one's feet' when faced with an acute problem. This may be because it is not especially easy (nor ethical) to simulate convincingly acute threat, nor to position the experimental manipulation firmly between 'mild/chronic' and 'overwhelming/acute' threat, though both studies of the effects of stressors and the present thesis predict different responses to different levels of threat.

There are, however, very many studies of the effects of caffeine ingestion on different aspects of cognition. Despite this body of work, there are few clear cut findings of caffeine's effects in this area, whilst there is considerable ambiguity and conflict in the data. It is argued, however, that confusion is reduced if the perspective of caffeine use as an adaptive strategy is adopted, that is, that those tasks which might be expected to promote survival chances under threat, such as quicker response times or the identification of more false positives, will be affected by caffeine use.

In a comprehensive review of documented effects of caffeine on sensory-perceptual and cognitive tasks (excluding caffeine's effects on physical performance and mental performance-induced stress), Snel and Lorist (1998) report that roughly half the studies examined, in any one aspect of a particular task, found significant effects of caffeine whilst the other half did not. Despite the conflict and ambiguity found, some general conclusions are possible: Van der Stelt and Snel (1998) report that caffeine improves performance on a wide range of cognitive tasks, such as learning, memory and attention tasks, when levels of alertness are less than optimal due to time of day, lack of sleep, post lunch dip, time on task, length of test session, upper respiratory tract illness or drug use. They conclude that caffeine's ability to counteract decrements in mental efficiency under reduced states of alertness is one of the more consistent findings in caffeine research (p. 181). Even so, the findings are not clear-cut. Beneficial effects of caffeine have been reported on several cognitive tasks under optimal as well as sub-optimal states of alertness, for example, on attentional tasks. Lorist, Snel, Kok and Mulder

(1996) report comparable improvement in performance across differing levels of alertness, so the notion that caffeine merely restores impaired cognition to a normal level is not tenable.

As far as attention is concerned, Posner and Peterson (1990) argue that attention relates to the way information is controlled. In attempting to understand the effects of caffeine on performance, researchers have utilised focussed/selective attention, divided/switched attention and vigilance/sustained attention experimental paradigms. Generally, neither visual focussed attention (i.e. 'filter') tasks nor visual search tasks are affected by caffeine. Mixed effects of caffeine have been found on a numerical version of the Stroop test, with Borland, Rogers, Nicholson, Pascoe and Spencer (1986) reporting no effect, Foreman, Barraclough, Moore, Mehta and Madon (1989) reporting negative effects and Hasenfrantz and Battig (1992) reporting positive findings. A little light was thrown on the Stroop results when Edward, Brice, Craig and Penri-Jones (1996), in a series of experiments, examined both the original colour-word version and the numerical version of Stroop, using both traditional card versions and computerised versions. No effects of caffeine were found, but the authors conclude firstly that significant practice effects were evident in the card version and secondly that the computerised version of the Stroop task is not an exact analogue of the traditional card version, in which case the contradictory findings in the area are hardly surprising. In divided attention/dual task paradigms, effects of caffeine are generally found only when participants are operating at sub-optimal levels, such as during the night. In other circumstances, no effect is found.

Overall there are many cognitive tasks which appear unaffected by caffeine ingestion, though an advantage in faster encoding and response to novelty in the environment (which caffeine ingestion promotes) appears evident, especially novelty that is focal and hence perceived as 'near,' or ambiguous and hence potentially threatening.

2.3.8. The Effect of Caffeine on Creativity and Cognitive Flexibility

Caffeine has been implicated in increased levels of creativity, Bach being so convinced of caffeine's ability to enhance creativity that he named one of his works the Coffee Cantata (BWV211). In addition, many writers, for example Balzac and Hemingway, are reputed to have drunk coffee very freely (Braun 1997). There appear to be no laboratory

studies demonstrating increased creativity under caffeine ingestion, though creativity is difficult to induce under controlled conditions. Since laboratory tests of creativity often rely on the ‘how many uses for a brick can you think of?’ paradigm, this lack is not necessarily conclusive. Kenemans, Wieleman, Zeegers and Verbaten (1999) found that caffeine increased cognitive flexibility, which may well be a prerequisite for creativity. There are no research studies of increased cognitive flexibility whilst under threat, though there are many war time anecdotes asserting ingenious behaviour whilst in danger.

2.3.9. Caffeine and Personality

There is evidence that caffeine ingestion may affect personality types differentially. Mitchell and Redman (1993) argue that caffeine disrupts natural biorhythms, particularly in extreme morning and evening trait individuals, resulting in negative mood states. Experimentally, caffeine’s effects have been shown to differ between extraverts and introverts (Liguori, Grass and Hughes 1999), chronotypes (Adan 1994) and a stability-lability dimension (Slanska, Grigorovova and Zvonicek 1978), whilst correlations of levels of caffeine use have been found with Type A-B behaviour (Hicks, Kilcourse and Sinnott 1983) and sensation seeking (Andrucci, Archer, Pancoast and Gordon 1989). In essence, no clear picture emerges from the considerable number of studies on caffeine use and personality, as many studies finding no effects of caffeine use on personality, as studies finding effects and it is argued that without a clear theoretical basis, it is unlikely that an improved understanding of the interaction of caffeine and personality will be found. It is hoped that the present thesis, underpinned by Polyvagal Theory, may offer the possibility of a better understanding of this issue.

2.4. Reported Detrimental Effects of Caffeine Use

Since it is being argued that moderate caffeine use in healthy adults is adaptive, evidence that normal caffeine use damages health would undermine the thesis, so it is appropriate to review studies which report negative effects of caffeine on health.

Reports of caffeine’s negative effects on physical health fall mainly within three areas: caffeine’s effects on cardio-vascular disease, on type 2 diabetes and on fertility. If there were mounting evidence for detrimental effects of caffeine on either of the first two conditions, this would constitute a counter argument to the idea that caffeine elicits

adaptive behaviours: however, this does not appear to be the case. There is mounting evidence that caffeine affects reproductive success but this supports, rather than detracts, from the theoretical underpinnings of the present thesis. Breeding is a costly undertaking in terms of physical resources, so may be maladaptive in an environment perceived as unsafe. This notion is supported by the fact that there is a reduction of secretion of sex hormones, resulting in lower libido and lower fertility in both males and females, during the fight-or-flight response.

On the other hand, caffeine use may protect against some cancers (James 1991), is associated with lower liver disease, including carcinoma (Gressner 2009) and is inversely related to suicide in some populations (Kawachi, Willett, Colditz, Stampfer and Speizer 1996), so the net effects of caffeine on health are difficult, if not impossible, to compute.

2.4.1. Caffeine's Effects on Cardio-Vascular Disease

Caffeine's potential effects on cardiovascular disease and the cardiovascular risk factors of serum cholesterol and blood pressure have been widely reported over the last twenty years. Some studies find significant associations between coffee drinking and CVD risk (Linsted, Kuzman and Anderson 1992), others find an inverse relationship (Kirchhoff, Torp-Pedersen, Hougaard, Jacobsen, Sjol, Munch, Tingleff, Jorgensen, Schroll and Olsen 1994) whilst some others report no relationship (Lancaster, Muir and Silagy 1994). In a comprehensive review James (1997) argues that, though interpreting the research record is not straightforward, extrapolation from epidemiological studies suggests that if caffeine use ceased levels of coronary heart disease would drop by approximately ten percentage. However, he stops short of explaining how he has reached this conclusion. Despite James' contention, there is surprisingly little evidence of physical damage by long term caffeine use in healthy adults. The data on caffeine use and CVD is contradictory: no clear relationship has emerged as it has, for instance, between nicotine use and lung cancer. In fact, the more recent studies, which accommodate a broad range of lifestyle factors, suggest that caffeine use has beneficial effects on CVD, despite the clear evidence that blood pressure and cholesterol are elevated (Zhang, Lopez-Garcia, Li, Hu and van Dam 2009).

2.4.2. Caffeine Ingestion and Diabetes

Similarly, it might be expected that caffeine's effect on the insulin response, that is, the frequent influxes of sugar into the bloodstream precipitated by caffeine ingestion, would, over time, result in type 2 diabetes mellitus, as it often does when a diet of moderate to high levels of sugar is consumed. However, counter-intuitively, Salazar-Martinez, Willett, Ascherio, Manson, Leitzman, Stampfer and Hu (2004), in a study of 42,000 men and 84,000 women, report the opposite: long-term coffee consumption is associated with a statistically significant lower risk for type 2 diabetes mellitus. In addition, a Finnish study of over 15,000 men and women concluded that coffee drinking (both filtered and non-filtered) has a graded inverse association risk of type 2 diabetes mellitus. Hence, there is no evidence of association of caffeine use and type 2 diabetes, other than a possible, presently unidentified, protective factor. This is in line with other recorded protective effects of moderate coffee drinking, for example the inverse relationship between coffee drinking and the irritation and sensitivity to light experienced in blepharospasm, which leads to blindness in extreme cases (Defazio, Berardelli and Hallett 2007).

2.4.3. Caffeine's Effects on Reproduction

The third major area of concern as far as caffeine's effects on health is concerned, caffeine's effects on reproductive success, is supported by research evidence. Hassan and Killick (2004) report dose-dependent effects of caffeine intake on time to pregnancy and Cnattingius, Signorello, Anneren, Clausson, Ekbon, Ljunger, Blot, McLaughlin, Petersson, Rane and Granath (2000) report more first trimester spontaneous abortions in women drinking more than 100mg of caffeine per day, compared with women drinking less than 100mg of caffeine. Males show a similar pattern of reduced fertility in relation to caffeine use, together with reduction in testes size and reduction in and damage to mature spermatazoa (Pollard and Smallshaw 1988). The above studies are correlational but Pollard, Murray, Hiller, Scaramuzzi and Wilson (1999) have shown experimentally in animals that caffeine ingested before ovulation reduces levels of maternal estradiol, which apparently increases pre-implantation losses and early, spontaneous abortions. In addition, they report that caffeine adversely affects the development of the foetus, bringing higher mortality during the first few days after birth, lower body weight at puberty and hence reduced reproductive potential. As long ago as 1980, the American Food and Drugs Administration (FDA) cautioned pregnant women against any level of

caffeine intake, in response to caffeine induced teratogenic effects in rodents (James 1997). There seems to be little doubt of the deleterious effects of caffeine ingestion on fertility and fecundity, though on the other hand caffeine is used successfully in therapeutic use in the treatment of neonatal apnea, stimulating 'at risk' newborns to breathe (Barrett and Rutter 1994).

2.4.3.1. Adaptive Value of Lowered Reproductive Success in a Stressful Environment

Caffeine creates the perception of threat, through the blocking of adenosine receptors and increased bodily arousal, and in evolutionary terms breeding when in a threatening and potentially unsafe environment is wasteful of resources: both the mother and the newborns are at risk, as ultimately, is the whole social group. Conservation groups all over the world report low breeding success when animals are stressed, whether in captivity or in the wild.

Since caffeine ingestion tends to increase when individuals feel themselves under stress (Ratliff-Crain and Kane 1995), such as when starting a new job, working with a difficult boss, or working in an area which is inherently stressful, such as the police force or armed services, it is possible to argue that the reduction in fertility and fecundity caused by caffeine use has the potential to be beneficial: the offspring of stressed parents are likely to be less healthy than those of unstressed parents. In addition, caffeine use creates not only the perception of threat but also releases resources, such as calcium, to help deal effectively with challenge, whether that threat is real or illusory. Hence, though the current medical guidelines to potential parents, of eliminating or reducing caffeine consumption until after the child is born, are clearly valid, it is argued that the notion that caffeine use is promoting a beneficial outcome in the long term is not entirely untenable.

The argument put forward by the medical profession and the media that caffeine use should be moderate, avoided by pregnant women and monitored in children and young adolescents is sound. It is, however, strange that caffeine consumption should attract so much research attention compared with other far more damaging substances, which are also consumed on a daily basis. For example, alcohol continues to be consumed frequently to excess, despite the attendant increase in violence in society, and

documented cognitive deficits of foetal alcohol syndrome caused by prenatal exposure. In addition it is becoming increasingly difficult to avoid consuming fluoride on a daily basis, despite the link to ‘subtle brain dysfunction’ (p. 151) noted by Mullinex, Denbesten, Schunior and Kernan (1996). A cursory glance at the research literature on the effects of fluoride exposure on the developing brain suggests that ‘subtle’ may be a considerable understatement, since low level fluoride ingestion has been linked with serious developmental disorders.

2.5. Summary

It is argued that the above sampling of the research literature with respect to the effects of caffeine ingestion offers *a priori* support for the notion that caffeine use enhances behaviours that increase the probability of survival.

In summary, following caffeine ingestion, vigilance is increased (Kamimori, Johnson, Thorne and Belenky 2005), input-perceptual and output-motor reaction time are facilitated (Lorist 1995), delays in the habituation of the human acoustic startle reflex are found (Schicatanio and Blumenthal 1995), perceptual-tactile judgements are facilitated (Gupta and Gupta 1994), the experience of pain is reduced (Diener, Pfaffenrath, Pageler, Peil and Aicher 2005), dual task performance is improved (Van Duinen, Lorist and Zijdewind 2005), there are increased numbers of false alarms to hits (Oei and Hartley 2005), fatigue is relieved (Davis, Zhao, Stock, Mehl, Buggy and Hand 2002) and anxiety in anxiotics is increased, whilst depression in depressives is lifted (Koelga 1993). In an aversive situation, all these changes are likely to be adaptive. Behaviours likely to identify potential danger, together with behaviours which remove an individual from a dangerous situation, such as running, are enhanced.

2.5.1. The Specificity Hypothesis

It is argued that the brief summary of effects, precipitated by both caffeine ingestion and the mammalian subset of survival behaviours described above, is sufficient to offer tentative support for the hypothesis that moderate caffeine use in healthy adults elicits adaptive behaviours. This is necessary but not sufficient: if caffeine simply enhances all physical and mental operations the present thesis would be unsupported. It is additionally necessary to show that caffeine’s effects are *specific* to behaviours that have the potential to promote survival, whilst caffeine does *not* enhance similar

(physical or perceptual-cognitive) behaviours which do not appear to be adaptive. As far as physical behaviours are concerned, the study of performance across a range of sports confirms that caffeine's effects are specific to those which, like running and cross-country skiing, enhance the ability to flee, as opposed to 'static' sports such as weight-lifting, which do not.

However, as far as perceptual-cognitive processes are concerned, the picture reflected by research is currently very far from clear. Hence, in the empirical work supporting the present thesis, a series of experiments is carried out in which, it might be expected theoretically, one experiment in the series examines a behaviour which offers adaptive potential and therefore may be expected to be enhanced by caffeine use, whereas other behaviours examined in the series do not. Specificity is central to the development and maintenance of adaptive behaviour and hence, if the present thesis is to be supported, it is imperative that a similar specificity is demonstrated with respect to the effects of caffeine ingestion.

Since it is not presently possible to link specific behaviours with examination of specific brain or neurological processes, in the current context the examination of behaviour appears to be the most fruitful way forward. Behaviour, however, does not extrude from a vacuum: the repertoire of behaviours available to any organism is constrained by the physiological systems which support the organism (for example, the brain and nervous system) and the totality of those available behaviours is subsequently modified by the environment. It follows that an appreciation of evolutionary theory, particularly with respect to the brain and regulatory systems is central to the current thesis. These issues are pursued in the following chapter.

Chapter Three

Evolutionary Pressures on Brain, Bodily Systems and Behaviour

3.1. Introduction

Since all thought and behaviour are both supported and constrained by the evolution of the physiological ‘software’ and ‘hardware’ which underpin them, a brief summary of those tenets of the perspective of evolutionary psychology deemed most relevant to the thesis, together with a consideration of the generally accepted biological evolution of the brain and regulatory systems, is made here. Initially, behaviours honed by evolutionary pressures are examined, followed by a selective consideration of the development of the primate brain and nervous and endocrine systems.

3.2. Mechanisms of Adaptation

The argument is being made that caffeine use elicits and promotes adaptive behaviours. Williams (1966) defines the concept of adaptation as an evolved solution (biological or psychological) to a specific, ancestral challenge, the solving of which contributes directly or indirectly to successful reproduction, and posits the defining criteria of such mechanisms as reliability, efficiency and economy. In support of William’s view, Tooby and Cosmides (1992) have argued that design features such as reliability (the mechanism normally develops in all members of a species and performs dependably), efficiency (the challenge is met successfully) and economy (the benefit is greater than the cost) could not have occurred simply through chance. Pinker (1997) has described the successful meeting of these criteria as improbable usefulness, whereas Darwin comments on the beauty of organisms’ ‘adapted(ness) to their habits of life’(in Ridley 1994, p. 9).

3.2.1. Survival Selection: Classical Fitness

Elements of what was to become Darwin’s theory of natural selection, or ‘survival selection’ as Darwin originally termed his theory, had been identified by earlier biologists, though they lacked Darwin’s ability to synthesise apparently disparate elements into a coherent and comprehensive theory. For example, the functionality, or seeming purposefulness of many structures, particularly in relation to defence, attack or obtaining, food had been noticed, as had the structural similarity of wings and flippers and, perhaps most compellingly, the remarkable similarity in embryological

development across classes of vertebrate, including frogs, birds and mammals, though the adult forms differ significantly, all of which argued for a common ancestry.

Darwin was able to demonstrate in his theory of natural selection a mechanism, differential reproductive success, through which different groups within a species could evolve away from one another and eventually form different species. No two creatures in the natural world are identical: of those variations which are heritable, some will be advantageous, or adaptive, whilst others confer disadvantage. Those offspring who inherit advantageous variation have an enhanced potential for survival and reproductive success, or 'fitness,' whereas those who inherit disadvantageous characteristics suffer the reverse consequences. Over time different kinds of variation may correspond with particular ecological niches (though according to Cronin, 1991, Darwin failed to appreciate the relevance of geographic isolation in this process) and, over many generations, different species develop from common ancestors. Darwin's exposition of the theory of natural selection (made jointly with Wallace, who had come to the same conclusions) in 1858 provided a plausible, if at the time largely unacceptable, explanation of the enigmas of the similarity of physiological structure and process amongst widely differing creatures and of apparent purposefulness or improbable usefulness of particular structures and behaviours.

3.2.2. Inclusive Fitness

Mendel's discovery, in 1864, of the particulate nature of inheritance (as opposed to the then current 'blending' assumption) and the later combination of the understanding of gene inheritance with the theory of natural selection (the 'modern synthesis', Dobhansky 1937; Meyr 1942) enabled extensions of Darwin's theory to account for complex social behaviours, which theorists had previously found very perplexing. Hamilton (1964) argued that the concept of classical fitness, that is, the measure of an individual's reproductive success, was too narrow to account for the process of natural selection, offering the alternative concept of 'inclusive fitness' which relies on the success of shared familial genes. This offers a putative rationale for altruism: when an individual assists a blood relative at a cost to himself, he may well be perpetuating his own genes, since family members are likely to carry copies of the same genes. The concept of inclusive fitness is interesting since, as well as having substantial explanatory power, it bridges the artificial conceptual divide between physiology and

behaviour: inclusive fitness is derived from a combination of the actions of an individual towards his genetic relatives together with his personal reproductive success.

3.2.3. Sexual Selection

In order to take account of apparent anomalies, such as the ‘wastage’ of resources tied up in a peacock’s tail, Darwin developed a second strand of evolutionary theory based on sexual selection, arguing that selection operates through two additional processes, intrasexual competition, in which the victor has access to females (and other resources, such as territory) and intersexual selection, based on female choice. Thus Darwin’s account of evolution offers mechanisms for the development of two classes of adaptation: the first, natural selection, offering a direct survival advantage and the second, sexual selection, offering a reproductive advantage. Although Darwin reports being much distressed by the ‘problem’ of the peacock’s tail, from today’s perspective, this issue may be redefined as the dearth of apparently excessive investment (such as the peacock’s tail) in not obviously practical features. Even within the avian world, such wanton ‘squandering’ of physical resources is relatively rare. Since this is the case, it becomes problematic to accept female choice based on physical appearance as a major driving force of evolutionary change.

3.2.4. Multilevel Selection

An alternative mechanism was put forward by Wynne-Edwards (1962), in the notion of group selection, that is that alleles, or versions of genes, may become fixed in or spread throughout a population, regardless of the fitness of individual group members, because of the benefits conferred by the alleles on the whole group. When originally mooted as an additional mechanism through which adaptations might develop, the theory was subjected to fierce criticism, particularly from Perrins (1964) and Williams (1966). However, much of this early rejection appears to have been based on inadequate theorizing and flawed statistical analysis (Mitteldorf, Croll and Ravela 2002) together with insufficient observation of real world effects and experimental results (Gilpin 1975). Experimental work which began in the 1970s showed that group or multilevel, selection, as it is now more usually called, is in fact a more cogent force than earlier models had suggested (Wade 1977), whilst the power of the gene-centred, or individual, model of the development of adaptation has been overestimated (Werfel and Bar-Yam 2004). Not all evolutionary psychologists (for example, Dawkins 1994; Dennett 1994)

agree that the tide has turned in favour of multilevel selection as an additional, powerful mechanism of selection, but evidence appears to be accumulating in its favour. Multilevel selection also offers a mechanism for the development of reproductive and predator restraint: a predator which is too successful may leave its offspring insufficient to eat.

3.2.5. Mechanisms of Cooperation and Control Amongst Non-Kin

Multilevel selection offers an additional route for the evolution of behaviours previously considered problematic for the theory of evolution, for example altruism, a concept which had been seen as something of a conundrum for the gene-centred perspective. Hamilton (1964), when discussing helping behaviour amongst kin, argued that if the benefit to the relative, multiplied by the probability that a gene is shared, exceeds the cost of the helping behaviour, then the 'helping' gene will spread throughout a population. However, everyday experience offers many demonstrations of benefits conferred on non-kin. In trying to identify a mechanism which would account for this behaviour, Axelrod and Hamilton (1981) devised the theory of reciprocal altruism, which argues that so long as a benefit is repaid at some time in the future, psychological mechanisms for reciprocation and social exchange will be adaptive. Cosmides and Tooby (1992) have defined reciprocal altruism as cooperation for mutual benefit between two or more individuals. Multilevel selection however has wider implications and is able to account for cooperative alliances between groups very distantly related. It is no longer necessary for the beneficiary to be a close relative, nor for the beneficiary to repay the individual benefactor: altruistic genes within the group confer an adaptive social climate.

This process offers a mechanism through which the historic 'Tragedy of the Commons' (in which the right to graze animals on common land results in overgrazing and loss of pasture for all, due to individuals taking the maximum benefit for themselves and thus damaging the common good, Hardin 1968; Lloyd 1833) may be ameliorated, if not completely avoided. However, Wilson and Dugatkin (1997), after reviewing a number of experimental papers, conclude that the upper number for such a system to work effectively may be as low as 150 people. If this is the case, it may go some way to explaining why the modern world has so many examples of 'tragedies', such as over-

fishing, over-logging and traffic congestion. Our behaviours, and the physiology which underpin them, evolved in a very different world from that of the present.

3.2.5.1. Individual Benefit Versus Whole Group Benefit

If multilevel selection proves to be as cogent an adaptive mechanism as its proponents presently argue, questions will arise as to the ways in which groups consciously and unconsciously maintain a balance between the good of the individual and the good of the group. In social insects this dichotomy has been solved by evolution through the inability to breed of worker status insects. In vertebrates there appear to be multiple mechanisms, involving different structures of the brain, underpinning the development of altruism. One strand of research, utilising fMRI whilst participants played computer games in order to earn money for real charities, shows a part of the ‘old’ midbrain (the fronto-mesolimbic network), more usually associated with the desire for food and sex, lighting up in response to altruistic decisions (Moll, Grafman and Krueger 2006). Another study (Tankersley, Stowe and Huettel 2007) connects altruism with activity in the posterior superior temporal cortex, which is more usually associated with the ability to perceive the goals and intentions of others. Both of these seats of brain activity in relation to altruism argue for an ancient aetiology, far beyond the development of hominids.

In addition to these unconscious ‘hard-wired’ responses, in primates there are a number of conscious strategies, such as the restriction in humans (at least in theory) to one breeding partner at a time, and the mirroring of responses seen in Tit-for Tat behaviours, described by Axelrod (1984).

Axelrod held a worldwide computerized tournament of the ‘iterated prisoner’s dilemma’, in which he found that strategies for short term gain were rejected in favour of long-term cooperation (which is very different from the misguided ‘nature red in tooth and claw’, still sometimes cited as evolutionary theory). The simple strategy of Tit-for-Tat won the tournament and Axelrod was able to use this phenomenon to explain previously puzzling instances of spontaneous cooperation between warring humans in very difficult circumstances. For example, a curious phenomenon had been noticed in the study of trench warfare in World War I, in which each side would shell one area only of the enemy trench at regular intervals, hence allowing the other side to

take cover in good time. Both sides were seen to be doing their duty by superior officers and thus avoided being court-martialled, but through cooperative behaviour, the men most at risk were able to gain a measure of protection for themselves.

3.2.5.2. Evolution of Moral Emotions

Another less conscious and less obvious mechanism of maintaining the balance between the good of the individual and the good of the group are measures of social control, such as the evolution of moral emotions. It is uncomfortable to experience guilt, shame or embarrassment privately, but doubly so to do so publicly.

An experiment which demonstrates the power of moral emotions, or group monitoring of behaviour, and the extent to which human brains have evolved to 'play fair', at least in public, is provided by Bateson, Nettle and Roberts (2006). In the coffee room of a university, tea, coffee, milk and sugar were provided, together with a suggested price list (30, 50 and 10 pence) close to an honesty box for voluntary contributions. The layout of the room was such that it was not possible for the actions of anyone in the room to be observed, that is, contributions to the honesty box were completely anonymous. Across the top of the price list images were displayed that varied, on a weekly basis, between pairs of eyes and flowers. At the end of ten weeks it was found that contributions always increased with the transition from flower images to eye images and decreased when the image changed from eyes to flowers. The authors conclude that concern over reputation is a powerful mechanism driving cooperative behaviour and that 'the self-interested motive of reputation maintenance may be sufficient to explain cooperation in the absence of direct return' (p. 3).

An earlier laboratory experiment (Haley and Fessler 2005) had shown that participants, even when told they were not being watched, responded in a similar way to subtle eye-like spots in the background of the computer they were using. It appears that the human brain, which contains neurons sensitive to face and eye images (Emery 2000), and nervous system has evolved not simply to monitor the behaviour of others, but also to be aware that others monitor us. Although it is clear that cues of being watched enhance cooperation, it will be argued below that the presence of caffeine in the body is likely further to increase cooperative behaviours.

3.2.5.3. Social Contracts

The evolution of an optimal balance between the costs and benefits of group living appears to have arisen through the development of a variety of psychological adaptations which permit social monitoring. In addition to the sensitivity of the perception of being watched (Cosmides and Tooby 1992), it has been demonstrated that there is a cognitive mechanism, 'a cheater detector' (based on IF-THEN decision rules), that monitors the honouring of social contracts, both in 'normals' and brain-damaged patients (Stone, Cosmides, Tooby, Kroll and Knight 2002), which has the potential to prevent, or reduce the incidence of, selfish individuals exploiting the resources of the group to which they belong. Similarly, Price has argued that psychological mechanisms have evolved to deter defection and free-riding in cooperative alliances, culminating in the development of the 'punitive sentiment', which, when made operational, both damages the freeloader's fitness compared with fully participating alliance members and encourages reluctant contributors to participate, hence 'eliminat[ing] adverse fitness differentials' (Price, Cosmides and Tooby 2002, p. 210). The 'cry for justice' howl that emanates from the press, especially from the 'redtops,' for sterner punishments for those who break society's rules may well sell newspapers, but equally may damage the fitness of the offenders, particularly in settings where groups are small enough to be monitored easily, or where there is a cultural obligation to fit in with others, such as is found in non-individualistic societies like that of Japan. Doubtless, there are other mechanisms of group, or social, control yet to be identified or yet to be considered in this specific context, but it is beyond the remit of the present thesis of caffeine use as an adaptive strategy to pursue this line of reasoning further here.

3.2.6. Evolution of Fear, 'Stress' and the Perception of Threat

Successful adaptations confer fitness, that is, a survival advantage. In order to survive danger it is necessary to become aware of threat and hence the evolution of the psychological experience of fear, in response to potential realistic danger, is a cogent adaptation. As Marks (1987) argues persuasively, 'Fear is a vital evolutionary legacy that leads an organism to avoid threat, and has obvious survival value. ... Fear ... alerts us to perform well under stress.' (p. 91). The subjective experience of fear triggers a set of evolved adaptive physiological reactions, such as the release of epinephrine and increased heart rate, clearly seen in the 'fight-or-flight' syndrome described below. The pattern of evolved physiological responses brought about by the awareness of threat

appears to be identical to those elicited through the experience commonly described today as ‘stress’: there may be quantitative and qualitative implications in the choice of one word over the other, since ‘fear’ tends to be preferred over ‘stress’ when the threat is perceived as very direct and immediately life-threatening, whereas ‘stress’ is preferred when the threat is perceived as more diffuse, and chronic rather than acute, but this is a matter of semantics rather than actual differences in physiological states. The body’s physiological responses and the behaviours associated with them in response to ‘stress’ are the same as those experienced when perceived threat makes us fearful.

This brief introduction to some of the insights offered by the perspective of evolutionary psychology may be sufficient to demonstrate that much of what we consider sophisticated, modern behaviour has its roots in that most ancient of instincts, the instinct to survive. The physiology which underpinned the successful behaviours of our ancestors when meeting threats to their survival still serves us well for much of the time and appears to be unchanged since well before the emergence of *Homo sapiens*: the brain, nervous systems, striate musculature and endocrine system that protected our earliest human ancestors protect us still. In fact much of this physiology, and many of the behaviours associated with it, appears to have its origins in creatures far older, in evolutionary terms, than *Homo sapiens*.

3.3. Evolution of the Primate Brain

Since primates share the adaptive problems of subsistence behaviours, such as finding food, shelter, mates and reproduction, with many other animals whose ancestry is much older, it might be expected that similarities in brain structure and process would be found across classes in a particular phylum and even across phyla.

3.3.1. The ‘Triune’ Brain Hypothesis

Inferring the evolution of the human brain is fraught with difficulty. However, for illustrative purposes, it may be worthwhile to revisit MacLean’s (1978) much criticised (Pinker 1997) notion of the ‘triune’ brain. Commenting on the remarkable concordance of structures in the human brain with those of evolutionarily older animals, MacLean concludes that, whilst having an enlarged forebrain, the human brain retains ‘the basic features of three formations that reflect our ancestral relationship to reptiles, early mammals and recent mammals,’ (p.308) and that these ‘three formations constitute a

hierarchy of three brains in one ... or a triune brain,' (p. 309), these three 'brains' being the Reptilian (or R) complex, the Limbic System and the Neocortex.

There are obvious problems with MacLean's argument: there is a concordance between human limbs and those of alligators or the 'flippers' of lungfish, but it is clear that whilst evolutionary pressures have retained the basic structure of a limb, they have also been the source of considerable modification. So it is with the human brain: the human neocortex has (arguably) given rise to consciousness and rationality and is the source of incredible intellectual achievement, but highly modified versions of evolutionarily older brain systems, and the involuntary emotional and behavioural responses associated with them, still reside within the modern human cranium, sometimes seeming to control our behaviour. For example, road rage may be seen as one of several modern behavioural phenomena, which may arguably be construed as being driven by an aggressive behaviour complex derived from the ancient fight-or-flight response.

Despite a number of errors in the Triune Brain Hypothesis (Caine and Caine 1990), MacLean's central insight, that some brain structures and the behaviours associated with them have been conserved across phylogenetic change, is both accurate and important. Indeed, there appears to be a newly emerging consensus of the value of MacLean's work, Porges (2003) arguing that it makes an important contribution to knowledge in three important areas: firstly it draws attention to the importance of evolution as an organizing principle in both the development of the nervous system and the social behaviour which it underpins; secondly it legitimises the biological perspective in the study of emotion; and thirdly it recognises the importance of vagal afferents (or feedback) to higher brain function. If this consensus is accepted, together with Jackson's (1958) theory of dissolution, MacLean's work (and more recent developments such as Polyvagal Theory) offers the potential to explain a number of human behaviours, initiated by the stressful perception of threat, for which we otherwise have no compelling rationale.

3.3.2. Evolutionary Homologies

Minkoff (1983) refers to similarities between organisms that are the consequence of common ancestry as evolutionary homologies. MacLean's hypothesis that evolution is

directional (MacLean 1978), a step-like progression from primitive reptilian brain and behaviour to a human, teleological peak, rather than all animals being perfectly adapted to particular environmental niches, is clearly false, but the notion of homologies in brain and behaviour is accepted as valid. For example, the existence of clade level, neuroanatomical-behavioural complexes has been supported McKinney (2000), and Allman (2000) reports that throughout vertebrate evolution ‘the network of serotonergic neurons in the brainstem [which] was present in the earliest vertebrates ... has retained a remarkably anatomical constant position,’ (p. 5). This is not to argue that because humans share with reptiles what MacLean calls the ‘R-complex’ (brainstem and cerebellum) we will necessarily start snapping our jaws menacingly under perceived threat. However, these ‘reptilian’ brain structures are strongly implicated in survival behaviours, such as ‘fight-or-flight’, reproduction, social dominance and the acquisition and defence of territory, all of which are issues which exercise the modern human brain considerably. In fact, it has been persuasively argued by Kravitz (1988) that animal evolution has been accompanied by progressive adaptation to the neurobiological response to threat, from invertebrates to primates.

3.3.3. Primate Brain Size

This being the case, it might be expected that primates in general and *Homo sapiens* in particular, would exhibit an additional level of neurobiological structures (and accompanying behaviours) in response to threat, not because they are in any way superior to animals that are evolutionarily older, which have developed their own optimal threat survival systems, but simply because of their relatively recent evolution. In fact this is the case, in terms of both brain size and specific brain structure. Primates devote more of their energy than other species to costly brain development and develop larger brains than either body mass or maternal basal metabolic rate would predict. In addition, the brains of larger primates have a greater degree of folding than would be predicted from the overall volume of their brains (Zilles, Armstrong, Moser, Schleicher and Stephan 1989). The increased area and greater connectivity of the deeply fissured primate neocortex offer sufficient computing power for the resolution of additional adaptive problems, which suggests that primates during their evolution faced a specific class of additional adaptive problems, not faced by most other animals.

In fact the disproportionate size of the brains of primates in general and *Homo sapiens* in particular has been the source of considerable speculation. It has been argued that large brains inevitably develop in response to large bodies (Finlay and Darlington 1995), that fruit eating, as opposed to leaf eating, imposes greater cognitive demands in the requirements for improved colour vision for the correct identification of ripe fruit and better cognitive mapping for the finding of fruit (Clutton-Brock and Harvey 1980) and that 'spare' maternal energy over basal metabolic requirements is channelled into foetal brain development (Martin 1981).

3.3.4. The Social Brain

However, a consensus has emerged that disproportionate brain size is driven by the need for highly social animals to monitor the behaviour of other conspecifics towards themselves and others. Such monitoring involves tactical deception (Byrne and Whiten 1988) and the formation and maintenance of coalitions (Harcourt 1988). Dunbar (1998), in his elegant and comprehensive paper, *The Social Brain Hypothesis*, argues persuasively that, because they are so costly, 'Large brains will evolve only when the selection factor in their favour is sufficient to overcome the steep cost gradient' (p. 179) and that only the benefits of living in a large social group are able to do this.

However, there are risks as well as benefits from belonging to a large social group and, according to Dunbar, it is the sophisticated social skills necessary for successful group living, for example, 'those fine nuances of meaning that create both the ambiguities of politeness and the subtleties of public relations' (p. 189) that have driven the development of disproportionate brain size in primates. Language in general, and gossip in particular, according to Dunbar (1996) is a sophisticated system for keeping track of who is doing what to whom in a relatively large social group, superseding the grooming which serves a similar purpose in other primates.

Language seems ideally suited to this task, as the unexpected (to mobile telephone manufacturers) explosion in texting among young people illustrates, but seems not, in itself, to be able to account for the increased thickness of the human neocortex. Evidence for this is found in the fact that there are relative differences in cortical thickness between monkeys, whom Dunbar describes as being good ethologists, since they excel at reading behaviour, and apes, whom Dunbar describes as being good

psychologists, since they excel at reading minds. Actually, O'Connell (1996) reports chimpanzees, close relatives to humans, showing evidence of a theory of mind through their performance on false-belief tasks, though neither non-human apes nor monkeys have spoken language. In addition, the social brain hypothesis is supported by the comparative cortical thickness of animals far removed from primates: amongst the very many kinds of bats studied, the vampire bat, which is distinguished from other bats by its highly social life style, has a substantially thicker cortex than any of the other, less social bats.

There are, of course, many advantages of living in a social group, including food and knowledge sharing, opportunities for finding a mate and the greater probability of a sizeable group being able to defeat predatory animals or an aggressive, rival tribe. However, there are also problems of group living: in our ancestral past, as now, the greatest threat to our well-being, and hence a major adaptive problem, is the behaviour of fellow group members. It has been suggested (Parker and McKinney 1999) that seriation, the ability to rank order objects, ostensibly a purely cognitive function and one which is found in only primates, probably evolved in order to track dominance hierarchies. In group living there is inevitably a degree of conflict over resources: there may be a direct physical or psychological threat to our well-being, to our physical resources, to our reputation or standing in the community or the workplace or to our family: in any of these cases the victim will feel fearful and stressed, yet may well have to remain within the group since social animals cannot prosper or survive for long without the support of a group.

3.4. Connection and Regulation: the Central Nervous System

The physiological and biological responses to stressful situations, which have been honed by evolutionary pressures, are much studied and understood in some depth but, as Gevartz (2007) notes, constitute 'an enormous topic' (p. 53). Consequently the brief summary presented here is inevitably inadequate, but may be sufficient to support the thesis that elements of the human response to threat (or novelty perceived as potential threat), which is orchestrated by the brain and regulatory systems, are elicited by caffeine use.

Conventionally, the nervous system is seen to consist of two main divisions, the central nervous system (CNS), consisting of the brain and spinal cord, and the peripheral nervous system, consisting of the somatic/sensory system and the autonomic nervous system (ANS). In turn, the ANS has two branches, the sympathetic (SNS) and parasympathetic (PNS) nervous systems. The ANS is activated primarily by the spinal cord, the hypothalamus and the brainstem and down regulated by the orbitofrontal cortex, through the neurotransmitters norepinephrine and acetylcholine. Although the SNS and PNS are conceptualised as separate, they interact constantly in complex patterns of excitation and relaxation and the term 'tone' has been used to describe the way in which this interplay is thought to keep target organs in optimal mid range values.

3.4.1. Neural Regulation in Response to Threat: the Polyvagal Theory

Despite the enormity of the topic, a compelling and comprehensive attempt to understand and explain physical and psychological responses to perceived threat has been made by Porges through the development of Polyvagal Theory (Porges 1995; 1997; 1998; 2001, 2007). Porges has published in excess of two hundred papers relating to the development of Polyvagal Theory and its applications, the earliest in 1969 being *Respiratory and heart rate components of attention*. Clearly it is impossible to do justice to this significant scholastic output within the confines of the present thesis, but it is considered important to attempt to summarize the theory in some detail, since the argument that caffeine elicits mammalian threat responses, hence accessing physiological and psychological resources not normally available, is central to the specificity hypothesis. Polyvagal Theory delineates clearly the process and structure underlying the mammalian response. The following attempt to summarize Polyvagal Theory is based primarily on the following papers: *Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A Polyvagal Theory* (Porges 1995); *Emotion: An evolutionary by-product of the neural regulation of the autonomic nervous system* (Porges 1997); *Love: an emergent property of the mammalian autonomic nervous system* (Porges 1998), *The Polyvagal Theory: Phylogenetic substrates of a social nervous system* (Porges 2001) and *The Polyvagal Perspective* (Porges 2007).

In the same way that the brain, under evolutionary pressures, developed additional structures which overlay earlier brain structures, so too has the system of neural

regulation become more complex and extensive as older neural circuits were modified and overlain by newer systems. Early or 'primitive' vertebrate brains (looking similar to the modern human brainstem) consisted predominantly of reflexive neural circuits, evolved to protect visceral function (e.g. of heart, lungs, gut etc.) whilst conserving metabolic resources. As organisms evolved, the reflexively wired neural circuits of 'older' creatures became intertwined with the more 'modern' and larger structures, which evolved in later mammals. There are two crucial differences between the original, reflexively driven, regulatory system and the later developing mammalian system: firstly the larger brains and increased neural complexity of the mammalian system fosters a wide range of behaviours in response to threat or challenge and secondly the latter has a high demand for oxygen (to support these behaviours), to the degree that if oxygen saturation of the blood drops, the system is seriously, and sometimes irreparably, damaged.

3.4.1.1. Mechanisms of Response to Environmental Challenge

The biological imperative of survival (and successful breeding) provides important challenges that must be met: the most urgent of these is to ascertain whether the environment is safe, at least in the immediate present. This determination is so important that mammals have evolved a cadre of behaviours, many of them below the level of human conscious awareness, which constantly sweep the environment for evidence of increased risk.

Allostasis is the term used to describe the process of adaptation which returns the body to homeostasis after threat in the environment has elicited a bodily reaction. Research interest in the past has tended to focus on the HPA (hypothalamus-pituitary-adrenal) axis and the sympathetic nervous system, such that the other component of the autonomic nervous system, the parasympathetic nervous system, in which the vagus nerve is the major 'carrier' or 'highway', has to some extent been neglected. In mammals two vagal components have evolved in the brainstem, the dorsal vagal complex (DVC), which controls parasympathetic function below the diaphragm, and the ventral vagal complex (VVC), which controls functions above the diaphragm, such as those of the heart, thymus and lungs. At times of environmental challenge the vagal brake (VVC inhibition) is disengaged, increasing heart rate and metabolism and

allowing appropriate action. This occurs without the involvement of the adrenal system or sympathetic nervous system.

Porges uses the term ‘neuroception’ to describe the subconscious system for detecting threats or safety. These behaviours, or neuroception, input a complex feedback loop in which physiological state and subjective experience influence, and are influenced by, the perception of threat. For example, brainstem structures and autonomic neural pathways, which monitor and control visceral state, communicate with the heart, lung, gut etc. passing visceral afferent information to higher brain structures, which in turn influence neural efferent (‘command’) information returning to those same visceral organs. Hence subjective experience of the present environment influences physiological state, whilst physiological state affects which behaviour from the available repertoire an animal may employ. Darwin (1871) recognised the importance of this bidirectional flow of information:

...when the mind is strongly excited, we might expect it would instantly affect in a direct manner the heart...when the heart is affected it reacts on the brain; and the state of the brain again reacts through the pneumo-gastric [vagus] nerve on the heart; so that under any excitement there will be much mutual action and reaction between these, the two most important organs of the body (p. 69).

Hence whilst awake (and to some extent during sleep), our physiology constantly monitors the environment for threat. The process may be summarized as follows: when the environment is perceived as *slightly threatening*, during ‘stress’, the vagal brake, or vagal inhibition, is relaxed and then reactivated during recovery, when the threat is passed. When the environment is perceived as *moderately stressful* the vagal brake is again released whilst the activity in the HPA axis increases. During recovery these two actions are reversed and a feedback loop develops. During *very severe stress* the vagal brake is again disengaged, the HPA activated but the feedback loop breaks down, leading to decreasing activity in the dorsal vagal complex, immobility and eventually death.

In order to decide whether an environment is presently safe, social animals must be able to distinguish between friend and foe (or predator) and to engage with their social group (to ask for help, to warn of predators, to maximize foraging, etc.). According to Polyvagal Theory, over time these environmental challenges resulted in the development of three classes of behavioural strategies, depending on the complexity of the animal (death feigning/behavioural shutdown, fight-or-flight mobilization and social engagement).

Underpinning these classes of behavioural strategies are phylogenetic differences in the vagus, the tenth cranial nerve that channels information to the parasympathetic branch of the autonomic nervous system. Early 'primitive' vertebrates have an unmyelated vagus, the 'vegetative' vagus, which orchestrates immobilization behaviours such as death feigning and passive avoidance, whilst mammals have both myelated and unmyelated vagi, supporting much broader repertoires of behaviour. In later mammals the vagus differentiates into several neural pathways, originating from different areas of the brainstem and consisting of primarily (80%) afferent ('feedback') pathways. With increased cortical development greater control is exercised over the brainstem through direct (corticobulbar) and indirect (corticoreticular) neural pathways (Porges 2001).

In effect, the PNS in Porges' (1995; 2007) Polyvagal model is seen to have distinct branches: a vegetative vagus, which under threat tries to shut down the cardiovascular system, as during the diving reflex and a 'smart' vagus which is an adaptation to 'novelty in the environment while coping with the need to maintain metabolic output and continuous social communication' (p. 310). The smart vagus is of particular interest in considering human responses since it underpins the Social Engagement System through feeding into cranial nerves (V, VII, IX, X and XI), which enable facial expression, head turning and vocalisation, through control of the larynx, phalanx and mouth and jaw muscles.

However, as Jackson hypothesised, in response to disease or other insult, higher brain systems are inactivated whilst lower ones are disinhibited ('evolution in reverse'). As Porges reports in describing the phylogentic hierarchy of response to challenge, the newest circuits (in evolutionary terms) are used to promote calm states, to self-soothe and to engage socially. If these behaviours do not dispose of the challenge or threat,

then the sympathetic-adrenal system over-rides them so that mobilization fight-or-flight behaviours are promoted. If these too should fail to deal with the challenge, then the oldest vagal shutdown (or freeze) system becomes operational. Crucially, Polyvagal Theory (Porges 2007) argues that dissolution may also occur as an adaptive response strategy. Since an individual's ability to mobilize fight-or-flight behaviours is compromised by cortical control, under threat it may be adaptive for these controls to be disinhibited so that the sympathetic nervous system can increase metabolic output (in order to flee). Inevitably this disinhibition compromises later-developed structures associated with social behaviour, calm physiological states and communication.

3.5. Theories of Stress and Polyvagal Theory: a Brief Historical Review

Polyvagal Theory, in addition to being a source of successful interventions for a range of developmental problems, such as autism and other learning disorders (Porges 1998), offers the potential to throw light on competing historical theories of the underlying mechanisms of stress (although Porges has not chosen to use the theory to do so).

3.5.1. Early Perspectives on Fear and the Perception of Threat

Despite much scholarship devoted to the topic of stress, arguably the most influential theories historically are the opposing perspectives expressed in the James-Lange (James 1884) and Cannon-Bard (Cannon 1927; 1928) theories. James argued (1890) that 'bodily changes follow directly from the perception of an exciting fact and that our feeling of the same changes as they occur *is* the emotion', that is, that visceral sensation occurs and preorganised or reflex responses are engaged, prior to central nervous system processing (for example, the sight of a bear approaching promotes running, then fear, without conscious appraisal). James also argued that different emotions would be characterized by specific patterns of bodily change. Cannon rejected James' view of feedback from peripheral and visceral bodily responses driving action and argued that, on the contrary, exciting events were processed by the brain first, before being translated into emotion and bodily reaction, such as fear and flight. In the light of present knowledge, Cannon's rejection of visceral input and focus on sympathetic-adrenal excitation at the expense of the parasympathetic nervous system seems somewhat premature.

3.5.2. The Alarm Response or Fight-or-Flight

Cannon is credited with initiating description of the 'alarm response' the physiological response to threat, which later became known more commonly as the 'fight-or-flight' response. He considered it to be a hard-wired set of responses controlled by those parts of the brain and CNS which are oldest in evolutionary terms. Following on from these ideas, in 1942 Cannon became interested in the concept of 'voodoo death', attributing the phenomenon to shock caused by over excitation of the sympathetic nervous system and consequent excess of adrenaline. According to his model, the excess adrenaline would lead to rapid breathing and rapid pulse until the heart constricted permanently and the victim died in systole. Although the means to test his model were not available at the time Cannon was writing, in 1957 Richter set up an experiment with rats to test Cannon's hypothesis. From a modern perspective Richter's experiment is rather distasteful, revealing the dark side of psychological research, but it does add to knowledge in that it provided empirical data which contradict Cannon's model.

Rats, which had been pre-stressed by being handled and having their vibrissae cut, were placed in a tank of turbulent water from which there was no escape and time to death by drowning was recorded. Richter, who used two different samples of rats, 'domestic' laboratory rats and wild rats, found unexpectedly that the two groups behaved very differently. All the wild rats died within fifteen minutes, several diving straight to the bottom of the tank and not returning to the surface, whereas the laboratory rats lasted for several hours before dying eventually of exhaustion. Contrary to Cannon's hypotheses, all the rats died with engorged hearts, that is, they died 'vagal' deaths as the result of overstimulation of the parasympathetic system, and not from overstimulation of the sympathetic-adrenal system. However, since Richter was not able to offer a theoretical or physiological basis for this outcome, the implications of this experiment were not widely disseminated and Cannon's sympathetic-adrenal model of stress remained dominant.

With the benefit of subsequent research, it is possible to speculate that the wild rats, who had not previously been penned, handled or stressed by having their tactile whiskers cut, were more terrified than their domestic counterparts and consequently the evolutionarily newer mammalian stress response was 'rendered functionless', in Jackson's terms, so that the immobilization response (adaptive for reptiles but not

mammals) was the only one available to them. The laboratory rats, accustomed to being constrained and handled, may not have been as overwhelmed with terror as the wild rats and hence were able to access the mammalian mobilization response to threat and continued to swim for hours.

3.5.3. The General Adaptation Syndrome

Taking an historical view of the study of ‘stress’, a term coined by Selye, it is not difficult to reconcile Selye’s (1954) General Adaptation Syndrome with the fight or flight and freeze stages of Polyvagal Theory. The endocrine response systems underpin the General Adaptation Syndrome (GAS), which is based on homeostasis, during which stressors are dealt with effectively, but which when disrupted, as when suffering from long term or overwhelming stressors, leads to physiological ‘exhaustion’ and organ failure, just as in Polyvagal Theory older behavioural responses are elicited as newer responses break down. Selye based his model primarily on the results of experiments with animals in laboratories and on the effects of ‘first time’ parachute jumps in humans (that is, exposure to potentially life threatening events). These events demonstrated that perceived threat to homeostasis causes the adrenal cortex to release anti-inflammatory glucocorticoids, which modulate the consequences of trauma. A modern re-evaluation of Selye’s insight stresses the biphasic role of the adrenal steroids which both counter inflammation and set up buffers to protect tissues from overreaction (Munck, Guyre and Holbrook 1984). It is now known that stress hormones affect the brain in particular, as well as almost all other organs (Mendelson, McKittrick and McEwen 1993), that glucocorticoids check the noradrenergic arousal system, which may have an antidepressant effect (Gold, Goodwin and Chrousos 1988) and that prolonged exposure to uncontrollable stressors dysregulates serotonergic receptor sites, all of which may be seen as the ‘mechanics’ of the engagement and disengagement of the vagi, described in Polyvagal Theory.

3.5.4. Learned Helplessness, Depression and Post Traumatic Stress Disorder

The concept of ‘learned helplessness’ (Seligman and Maier 1967), which has been seen as analogous to human depression, developed as the result of ethically questionable experiments with dogs. In an attempt to understand the complexity of human learning through an operant conditioning paradigm, Seligman attempted to teach avoidance behaviour to dogs by the use of electric shocks. Dogs in the experimental condition

were yoked together in a harness and ‘pre-treated’ by being subjected to electric shocks: in each pair one dog was able to terminate the electric shock (and so had some ‘control’) whilst the other was not. In the experiment itself the dogs were released from the harness and, together with a control group, put into a ‘shuttle-box’ in which they could escape from electric shocks by jumping over a partition. A tone warning of the impending electric shock was sounded 10 seconds before the shock was administered and dogs in the control group and those who had previously been able to stop the electric shock learned to escape quickly, whereas two thirds of the dogs in the ‘no control’ position made no attempt to escape, remaining passive and appearing wretched, presumably having learned from the pre-treatment phase of the experiment that the forthcoming pain was not contingent on their behaviour. When the passive dogs were later physically dragged over the barrier when the warning tone sounded, most were eventually able to learn to escape, though in some cases dogs had to be manhandled over one hundred times in order to make the connection. Subsequent experiments demonstrated similar patterns of behaviour in human participants: for example Hiroto (1974) exposed human participants to loud, unpleasant, inescapable noise.

Seligman extended and ‘reformulated’ his original notion of ‘learned helplessness’ to a model of human depression (Abramson, Seligman and Teasdale 1978), which has been much criticised, Pratt (1980) for example pointing out that in human terms the dogs’ experience and behaviour is more similar to that of trauma victims than that of depressives. With regard to Polyvagal Theory, it is possible to speculate that dogs in the uncontrollable and inescapable shock condition were so terrified that the normal mammalian response to threat, that is, the engagement of the vagal ‘brake’ or decreasing cardiac vagal tone, broke down and gave way to the evolutionary older strategy of immobilization, through the vegetative vagus. There may be a similar process, analogous to PTSD and depression, in humans.

In support of this argument, cardiac vagal tone, that is the relationship between the brainstem and the heart and, more critically, regulation of vagal reactivity in response to environmental challenge, has been associated in humans with several kinds of psychological impairment, for example, with anxiety (Thayer, Friedman and Borkovec 1996), poor impulse control (Beauchaine 2001), hostility (Sloan, Shapiro, Bigger, Bagiella, Steinman and Gorman 1994) and recovery from major depression

(Rottenberg, Salomon, Gross and Gotlib 2005). In addition, in the rather different context of childhood behavioural problems, difficulties with engagement and disengagement of the vagal 'brake' have been shown to have serious behavioural consequences, for example, when they have been noted in nine month old infants, such difficulties have predicted behavioural problems at three years of age (Porges, Doussard-Roosevelt, Portales and Greenspan 1996).

Though there is much disagreement amongst researchers on the nature and process of 'stress', there is widespread agreement on the enormous cost of the experience, particularly in terms of the health of the individual and productivity for the employer, the latter consisting not only of work days lost but also of ongoing counterproductive work behaviours. Early approaches to the study of stress concentrated on the individual's response to threatening or disturbing elements of the environment ('response' theories), subsequent approaches on the specific nature of the disturbing stimulus ('stimulus' theories) and more recent approaches on an interaction of the two, that is, the lack of fit between the perceived demands of a situation and the individual's perception of available resources. A number of researchers argue that the degree of 'stress' experienced is dependent on an appraisal of the environment on the basis of threat to well-being, interference with goals or activity and attribution of the causes of the event (Lazarus and Folkman 1984; Spector and Fox 2004). This appraisal is unconscious to a greater or lesser extent.

3.5.5. The Perception of Control and Retention of the Vagal Brake

Despite their different approaches, early theories of stress were general, in the sense that they were all encompassing. Although this may be considered a strength of these theories, it reduced the likelihood of developing predictive models or effective interventions. Consequently, research on stress became more specific, in the sense of focussing on stress in particular spheres of life (such as work stress or the effects of stress on general health) or on different aspects of the presumed psychological processes underlying the experience of stress.

An important mediator in this process is the degree of control available in any situation. Averill (1973) distinguishes between *behavioural* control in which the characteristics of the threatening event may be modified, *cognitive* control in which the threatening event

is reinterpreted as potentially less harmful, *informational* control, in which prior signals warn of an impending aversive situation and *decisional* control, in which choice of action is perceived. Any and all of these mediators are likely to foster relaxation, so reducing the likelihood of vagal disengagement with the consequent loss of behavioural flexibility: hence control, or perceived control, is central to the understanding of stress and threat and to the notion of caffeine use as an evolved psychological adaptation. Humans reach for tea or coffee most often when they feel under par, in order to gain a sense of mastery over a potentially demanding situation.

3.5.5.1. Accessing the Perception of Control: Stress Inoculation and Cognitive Behavioural Therapy

The centrality of a sense of personal control in relation to the experience of stress has long been recognised in psychological research and very many different constructs have been developed in an attempt to encapsulate it. For example, Rotter (1966) developed the concept of locus of control, that is the extent to which individuals believe they are able (internal locus) or unable (external locus) to influence outcomes through their actions, whilst deCharms (1968) developed the construct of personal causation, Bandura (1977) the construct of self-efficacy, Pearlin and Schooler (1978) a scale of perceived control, mastery and empowerment, Friedland, Kienan and Regev (1992) the illusory control scale and Thompson, Schwankovsky and Pitts (1993) the decision involvement questionnaire. In addition many other constructs and scales have been developed for specific purposes, for example, perception of control over drinking or weight.

The impetus behind the vast body of work in this area has been the notion that an individual's scores on one (or more) of the appropriate scales might permit a degree of prediction, for instance with regard to health or employment outcomes, a notion that has been only moderately successful (Fox 2004). However, training in restructuring perceived threat using techniques such as SIT, or stress inoculation (Meichenbaum 1985), and CBT, or cognitive behavioural therapy (Beck 1976), whilst not offering prediction, have been found to be very effective in lowering stress levels and improving performance.

Research on the effectiveness of SIT has been demonstrated across a wide range of stressors: *acute time-limited* stressors such as surgery (Ross and Berger 1996) and

performance evaluation (Altaier, Ross, Leary and Thombrough 1982); *chronic intermittent* stressors, such as military combat (Meichenbaum 1994a); *chronic continual* stressors, such as found in police work or teaching (Meichenbaum 1993), and chronic illness (Randich 1982); and *stressor sequence*, or exposure to stressful events, such as rape, divorce or unemployment (Meichenbaum 1994b).

Although restructuring the problem *per se* is clearly the mechanism through which such interventions derive their efficacy, it is argued here that Polyvagal Theory offers an additional level of understanding to this process. The gradual reduction of perceived threat level through restructuring, as in stress inoculation or cognitive behavioural therapy, or the desensitising of phobias by progressively greater exposure to the feared object, is likely to facilitate the engagement and retention of the vagal brake, thus enabling a wider range of behaviours to be utilised.

3.6. Evidence from Brain Imaging Studies

Although the notion of the dissolution of evolutionarily newer behavioural patterns, underpinned by newer brain structures and an extension to regulatory systems, is coherent and logically appealing, there has, until recently, been little experimental evidence to support it. However, Mobbs, Marchant, Hassabis, Weiskopf, Seymour, Dolan and Frith (2007), in a complex yet elegant ‘escape pain’ virtual predator paradigm, report finding data that are extremely persuasive.

In the experiment, participants control a blue triangle (representing themselves) in a two-dimensional computer maze. Also in the maze is a virtual predator circle (reminiscent of the pacman of early computer games) which is coloured grey initially whilst wandering the maze aimlessly, begins to flash red/grey and then turns unblinkingly red during the chase/hunt phase of the game. These predator colour changes represent the three stages of what, in behavioural ecology, is known as the ‘predatory imminence continuum’ based on the immediacy of the threat. At stage one, ‘pre-encounter’, there is risk but no immediate danger, at stage two, ‘post-encounter’, threat has been identified and at stage three, ‘circa-strike’, the threat is perceived as life-threatening. Just prior to the point when the blue triangle is put under the participants’ control, they are informed that the ‘predator’ has the ability to chase, capture and inflict

three levels of (electric shock) pain on them. Throughout the trials brain activity was measured using functional magnetic resonance imaging (fMRI).

As both Polyvagal Theory and the Jacksonian theory of dissolution would predict, when threat has been identified but is still distant, activity is seen in the prefrontal cortex (anterior cingulate and ventromedial prefrontal cortex), suggesting that avoidance strategies are being planned and evaluated. As the threat becomes more imminent, activity shifts to phylogenetically older midbrain structures such as the periaqueductal grey which controls reflexive fight, flight and freeze behaviours, inhibiting the flexibility of behaviours available. Thus the closer threat becomes, the more reflex-driven or impulsive behaviour becomes.

3.7. Caffeine Ingestion and Polyvagal Theory

It is being argued that caffeine elicits the mammalian threat response, as described in Polyvagal Theory, that is that ‘surveillance behaviours’ such as vigilance, orientation and inspection are both faster and extended, that flight, should it become necessary, is facilitated and that social behaviours, such as individual and group calming and vocalisation or talking, are enhanced. In contrast other defensive behaviours such as fighting and freezing, found in phylogenetically older creatures, are not promoted by caffeine use, though under the Jacksonian principle, they may be elicited by severe threat.

3.8. Summary

This chapter has attempted to demonstrate the theoretical context for the argument that caffeine use promotes adaptive behaviours. Since it is being argued that caffeine use elicits specific threat-related behaviours, as opposed to more general effects, it was considered appropriate to outline, briefly, current understanding of the evolution of the brain, regulatory systems and threat response. In doing so, the opportunity for evaluation of the hypothesised aetiology of caffeine ingestion’s effects has been raised: this hypothesis will be tested empirically in the following five chapters.

Chapter Four

Levels of Caffeine Use and Personality Correlates of Caffeine Use in a Sample of Young Adults

4.1. General Introduction and Overview

Since there is a substantial body of literature attesting to the fact that caffeine ingestion has both positive and negative behavioural effects, it is seen as important firstly to ascertain levels of caffeine use (study 1) and secondly to test the specificity hypothesis with empirical data (study 2). Young people of reproductive age are utilised as a sample, since according to the literature caffeine use appears to be critical to reproductive success. As a first test of the predictive ability of the specificity hypothesis, habitual behaviour, or aspects of personality, are correlated with caffeine use, since the changed perception of increased threat caused by increased arousal may have measurable behavioural consequences. It has been argued that the increased neuroception of stress experienced under caffeine ingestion will shift neural regulation and action towards behaviours, such as increased wariness, that are likely to be adaptive in an environment of increased perceived stress. The personality traits of impulsiveness, empathy and venturesomeness, assessed through Eysenck and Eysenck's (1991) IVE scale, are examined since these are elements of behaviour that may show the impact of an increased perception of stress. Comparative studies show that in mice caffeine impacts on venturesomeness or exploratory and investigative behaviours (Meyer, Caston and Lieberman 2004).

The data for studies 1 and 2 were collected at the same time and from the same participants. In the interests of clarity, however, they are analysed and written up separately, firstly from the perspective of caffeine usage and secondly from the perspective of caffeine use and habitual behaviour.

4.2. Study 1: Levels of Caffeine Use in a Sample of Young People of Reproductive Age

Study 1 was designed to ascertain caffeine use in young people.

4.2.1. Introduction

It has been argued that, through its antagonistic effects on adenosine, caffeine increases arousal and that this increased arousal shifts patterns of neural regulation from those appropriate to a perceived safe environment to those appropriate to an environment perceived as potentially unsafe, eliciting mammalian survival stress response behaviours. Since it is documented that both the stress response and caffeine impair fertility and fecundity, it is particularly important to ascertain levels of caffeine use in young adults of reproductive age, which the current survey endeavours to do. Prior to this survey, no data relating to levels of caffeine use in this age group was available, although it appears such data may have important public health implications.

Much research into the effects of caffeine has focussed on improved cognitive performance and exercise endurance, especially in the elderly. For example, in a sample of 70 year olds who had abstained from caffeine for 48 hours and were then administered either placebo or caffeine (6 mg/kg), the experimental group, when tested one hour later, showed improvements of 25% in cycling endurance, 54% in arm flexion endurance and 25% in postural stability (Norager, Jensen, Madsen and Laurberg 2005). However, in other age groups caffeine's effects are not so positive. Caffeine use has long been associated with reduced fecundity in both males and females and recent experimental work with caffeine in animals has revealed causal mechanisms involved in reduced reproductive success (Bolumar, Olsen, Rebagliato and Bisanti 1997). Since fertility is an issue more relevant to sexually active, young adults, than to the elderly, it is seen as valuable to ascertain levels of caffeine use, age of onset of caffeine use and preferred caffeine vehicle in a younger, rather than older, age group. It is argued here, particularly in relation to caffeine's apparent detrimental effects on fecundity in both sexes, that since caffeine use is habitual, a better understanding of young people's use of caffeine has important public health implications.

4.2.1.1. Previous Surveys of Caffeine Use

Although the effects of acute and chronic doses of caffeine are well documented (Smith 2002), the extent to which caffeine is being used on an everyday basis across age groups is less clear. The main focus of most recent surveys of caffeine use has been on the elderly, Hughes and Oliveto (1997) reporting caffeine usage in a sample of seniors resident in Vermont; Jarvis (1993) reporting a positive correlation of cognitive

performance in old age with length of time of caffeine use; and Thompson, Rogers, Hayre and Jones (2003) reporting, in a survey of caffeine use in 158 older adults, that 96% of respondents consumed caffeine on a daily basis. Although Knibbe and De Haan (1998) report a survey of Dutch respondents 16-70 years old, details of coffee only, rather than total caffeine usage, were recorded and the data are not broken down across age groups. This lack of clear information on caffeine use in young people makes it very difficult to assess the putative positive and negative effects of caffeine use on the future reproductive health and well being of the young.

Hughes and Olivero's American study reports a survey of lifetime caffeine intake of 202 retired Vermont residents, noting that many older respondents had reduced their caffeine intake in the recent past, due either to health concerns or to unpleasant side effects, and concludes that questions about 'usual' coffee use provide a biased underestimate of lifetime caffeine use. They argue further that this may be of importance, since data about caffeine use are generally collected only in cases where degenerative disease, such as cardio-vascular ill-health, has already been identified and the underestimation of lifetime caffeine use may contribute to false-negative conclusions about caffeine's effect on health. If this argument is substantiated, there may be serious implications for the later health of young people presently ingesting caffeine at moderate or high levels. In the American study, it was found that 83% of the sample used one or more caffeinated beverages per week, with an average caffeine intake of 186 mg per day. The data were collected through a random-digit dial telephone survey.

In contrast, in the Dutch study, Knibbe and De Haan collected data through both diary and questionnaire measures. Useful though this study is, the fieldwork was carried out in 1985, which raises the possibility that coffee usage in the Netherlands may have changed over the last twenty years, so is of limited use when attempting to assess overall caffeine use in young adults today.

Thompson, Rogers, Hayre and Jones' more recent survey does report total caffeine intake, but relates to 158 older (mean age 74 years) healthy U.K. adults, who filled out questionnaires on caffeine use, and reports that older adults frequently consume relatively large (353 mg/24 hours) amounts of caffeine, which is substantially higher than the level Hughes and Oliveto found in their American study. The focus of the

research by Thompson, Rogers, Hayre and Jones is on the effects of caffeine consumption and withdrawal on cognitive performance in older adults, which is clearly of value, but again does not add to knowledge of the pattern of caffeine consumption in young adults of reproductive age.

There are clearly differences in patterns of consumption of caffeine containing foodstuffs across age groups. Valek, Laslavic and Laslavic (2004) report a caffeine survey of 500 ninth grade high school pupils in Croatia, where mean caffeine consumption was found to be 60 mg per day. Fifty percent of caffeine intake was derived from soft drinks, thirty-seven percent from coffee and thirteen percent from chocolate, which may be suggestive of a dependence on caffeine/sugar developing before adulthood. This is in line with Pollack and Bright's (2003) findings in which 190 American seventh, eighth and ninth grade school children had their caffeine consumption monitored, revealing a mean intake of 63 mg of caffeine per day, again derived primarily from cola soft drinks. Pollack and Bright report 'detectable pharmacological effects' (p. 42) associated with increased daytime sleep and reduced, disturbed nocturnal sleep. In fact both these groups of younger respondents are consuming the caffeine equivalent of only one cup of coffee per day, which may not be cause for any great concern, though that fact that children metabolise caffeine more slowly than adults results in potential toxicity at a much lower level than adult toxicity. The real issue of importance, in light of caffeine's known adverse effects on reproductive success, is at what stage in the lifespan average caffeine consumption inflates from the 60 mg per day found in children, to the 350 mg per day found in older adults by Thompson, Rogers, Hayre and Jones. If young adults of reproductive age consume an average of 60 mg of caffeine per day, the effect on overall reproductive success, though present, is likely to be negligible: If, however, they are consuming an average of 350 mg per day, the effects on fertility, fecundity and subsequent offspring warrant greater attention. The caffeine usage survey reported here addresses this important question.

4.2.1.2. New Study

In the present study, level of caffeine use, preferred caffeine vehicle and age of onset of caffeine ingestion are of primary interest, but it is seen as useful to ascertain whether associations of caffeine consumption with personal characteristics, such as age, sex,

chronotype and smoking, which have been noted elsewhere (e.g. Kole, Snel and Lorist 1998), exist similarly in a U.K. sample. Smoking is of particular interest, since smokers metabolise caffeine more rapidly than non-smokers and Warburton (1998) argues that caffeine and nicotine share both a common neurochemical mechanism and, to some extent, a common behavioural mode of action.

There is increasing interest amongst individuals, the medical professions and government in the physiological and psychological effects of the food and drink we ingest. The extended life-span (compared with previous generations) seen today in developed countries increases the likelihood that poor lifestyle choices, in relation to food and drink, will have adverse effects on health in later life (Thompson and Keene 2004). Any such poor decisions will inevitably incur large social and financial costs.

Caffeine, which has attracted particular interest, is most usually (and visibly) ingested in the form of coffee, tea, cola/caffeinated soda or chocolate. In addition caffeine is a constituent of a number of OTC drugs and 'energy' or 'stimulation' ctg (caffeine/taurine/glucuro lactone) drinks, is readily available in tablet form and is an ingredient in many sweet and savoury ready-made foods. Consequently it is almost impossible to avoid ingesting caffeine, knowingly or unknowingly.

4.2.1.3. Effects of Caffeine Use in Relation to Reproductive Success

Moderate caffeine use has been documented to confer many cognitive, perceptual and ergogenic improvements to performance in, for example, motor reaction time (Smith 1994), vigilance scores (Koelga 1993) and visual search (Durlach 1998). This may be particularly relevant to young people, since young males are over-represented in the statistics for accidents in general (Sproston and Primatest 2003) and for traffic accidents in particular (Bingham and Shope 2004) and enhanced performance on these aspects of cognition could, plausibly, improve their hazard perception. However, in the area of reproductive success, caffeine has been identified as a significant negative lifestyle factor. Hassan and Killick (2004) report dose-dependent effects of caffeine intake on time to pregnancy, when other negative lifestyle factors, such as smoking and alcohol consumption, had been accounted for, irrespective of coital frequency. Hakim, Gray and Zacur (1998) report that women who abstained from alcohol and consumed less than one cup of coffee or its caffeine equivalent per day, conceived 26.9 pregnancies per 100

menstrual cycles, compared with 10.5 pregnancies per 100 menstrual cycles for those who consumed any alcohol and more than one cup of coffee per day. That is, these authors are arguing that caffeine enhances alcohol's negative effects on reproductive success. Jensen, Henrikson, Hjollund, Scheike, Kolstad, Giwercman, Ernst, Skakkebaek and Olsen (1998) have calculated fecundity ratios (i.e. the ability to achieve a recognised pregnancy) of 0.88 for non-smoking women who consumed less than 300 mg caffeine per 24 hours, compared with 0.63 for non-smoking women who consumed 300-700 mg caffeine per 24 hours and suggest that women who are trying to get pregnant should consider reducing their caffeine intake. Males show a similar pattern of reduced fertility in relation to the amount of caffeine consumed (Jacombs, Ryan, Loupis and Pollard 1998; Pollard, Murray, Hiller, Scaramuzzi and Wilson 1999). More spontaneous, first-trimester abortions occur to non-smoking women ingesting at least 100 mg of caffeine per day, than to those ingesting less than 100 mg of caffeine per day (Cnattingius, Signorello, Anneren, Clausson, Ekbon, Ljunger, Blot, McLaughlin, Petersson, Rane and Granath 2000). Nawrot, Jordan, Eastwood, Rotstein, Hugenholtz and Feeley (2003), after reviewing the effects of caffeine on human health, suggest that reproductive-aged women should either abstain from caffeine or limit their consumption to less than 300 mg per day.

The above studies are mainly correlational, whereas Pollard (1996) has shown experimentally that, in animals, caffeine ingested before ovulation reduces levels of maternal oestradiol, which increases pre-implantation losses or early spontaneous miscarriages. In addition, she reports that caffeine adversely affects the development of the embryo and foetus, bringing higher mortality rates to rat pups during the first few days after birth and lower body weight at puberty. It is also reported that caffeine-lowered body weight at puberty may, in turn, affect the next generation's reproductive potential and that caffeine exacerbates the effects of other teratogens, such as nicotine and alcohol (Pollard 1996; Pollard and Smallshaw 1988). In humans also, caffeine intake is associated with the preterm delivery of infants (Klebanoff, Levine, Der Simonian, Clemens and Wilkins 1999). Pollard's contention that caffeine appears to depress reproductive hormone secretion in sexually active adult animals, reducing fecundity and possibly reducing fertility in the next generation, is an issue of concern and raises the possibility that caffeine consumption may affect hormone levels throughout the life cycle.

4.2.2. Method

In the current survey, an initial pilot study (n = 27) of the caffeine questionnaire devised for use in this study revealed substantial differences in reporting when respondents were asked about either daily or weekly consumption of caffeine. A later version of the questionnaire, which asked about both daily and weekly caffeine consumption, revealed significant inconsistencies. Information acquired during interviews indicated that participants were most confident of their replies when substances they usually ingested on a daily basis were enquired about within the context of a 24 hour timeframe and substances which they usually consumed less frequently were enquired about within a weekly timeframe. These findings were incorporated into the final survey instrument. In a bid to avoid or reduce experimenter effects, the survey was presented under the guise of the initial stages of a market research operation and questions were asked specifically about the types of coffee normally used. At the time of data collection, 'real coffee', that is, ground coffee, was a luxury apparently, generally beyond the pockets (or taste) of these students and responses referred to different types of supermarket freeze-dried or 'instant' coffee. Real, ground coffee was simply not part of everyday life for this sample of students at this time. Since there is no suggestion in the literature of differing amounts of caffeine being available from commercially available freeze-dried and 'instant' coffee, after inspection data on this aspect of caffeine consumption were discarded as being of no particular relevance to the thesis.

4.2.2.1. Design

A survey format is utilised for the design of study 1. A copy of the survey instrument is available in appendix ii.

4.2.2.2. Participants

An *ad hoc* sample of 181 undergraduates from Buckinghamshire Chilterns University College (BCUC), reading for either social science or computing degrees, served as respondents and were administered the questionnaires at the end of seminar or workshop sessions. The timing of data collection resulted in the very high return of 168 data sets (80 female, 86 male). The mean age of the sample was 22 years. 50

respondents described themselves as smokers whilst 98 described themselves as non-smokers.

4.2.2.3. Survey Instrument

The final version of the questionnaire asks about (caffeinated) coffee, cola/caffeinated soda, ctg cola and (caffeinated) tea use over a 24 hour period and about chocolate and caffeine tablets over a weekly period (see appendix ii). All categories of questions have memory probes relating to when the substance was last ingested and on what day(s) of the week it was normally consumed, in order to facilitate accurate recall. The questionnaire also records details of sex, age, and smoker or non-smoker status, since previous research on the effects of caffeine indicates that these attribute variables may interact with caffeine use.

4.2.2.4. Survey Procedure

The questionnaire was administered twice to each respondent, with an intermission of two weeks. To calculate caffeine intake, the following estimates were used, based on Barone's (Barone 1994; Barone and Roberts 1996) figures: brewed coffee = 85 mg/5oz cup, instant coffee = 65 mg/5oz cup, tea = 40 mg/5oz cup, cola = 40 mg/12oz can, ctg cola = 75 mg/12oz can, chocolate bar = 30 mg.

4.2.2.5. Reliability

A correlation coefficient of $r = 0.87$ was derived from the questionnaires for total caffeine consumption between the first and second questionnaires, indicating that the survey instrument has good reliability with this sample.

4.2.3. Results

The data are discussed in terms of levels of caffeine intake, preferred caffeine vehicle, overlap of caffeine vehicles and associated attribute variables.

4.2.3.1. Current Caffeine Intake

Over ninety-nine percent of respondents reported using caffeine on a weekly basis. Only one respondent reported not ingesting caffeinated products at all, stating 'cannot have caffeine on medical grounds' on the questionnaire. One other respondent reported not drinking caffeine, abstaining from all caffeinated beverages, but eating chocolate bars

on a weekly basis. However, there were substantial differences in the preferred source, or vehicle, through which caffeine was ingested. In this sample, most respondents reported drinking cola/caFFEinated soda and tea on a weekly basis, whilst just under half reported drinking coffee on a weekly basis (see Table 4-1). In addition, eighty-six percent reported eating chocolate bars on a weekly basis and thirty-two percent drinking ctg cola on a weekly basis. Fewer than one percent of respondents reported taking caffeine tablets on a weekly basis. The argument that non-beverage caffeine intake, for instance from chocolate and medications, is negligible, contributing less than five percent of total caffeine intake (Barone and Roberts 1996; Gilbert 1984) is largely supported by the current study's findings, since the mean intake of chocolate bars here is reported as 18 mg/24 hours, which amounts to approximately five percent of mean total caffeine intake.

Table 4-1: Prevalence (percentage) of Weekly Use of Caffeine Vehicle Amongst 168 Respondents

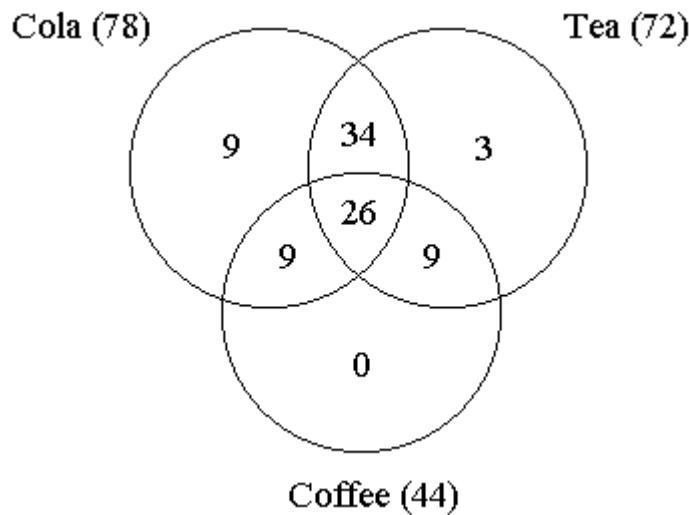
Source	Percentage
Any caffeine source	99%
Chocolate bars	86%
Cola/soda	78%
Tea	72%
Coffee	44%
Ctg cola	32%

In addition, considerable overlap in caffeine vehicle was reported (see Figure 4-1), most respondents using more than one caffeinated beverage on at least a weekly basis, for example, drinking cola plus tea (60%) or cola plus both tea and coffee (26%).

Although chocolate and cola/soda were the most frequently ingested sources of caffeine, they were not the highest sources of caffeine. The majority of respondents in this sample obtained most of their caffeine intake from tea or coffee. Mean daily intake of caffeine from tea was found to be 228 mg/day, from coffee 202 mg/day and from cola/soda 97 mg/day (ctg cola 47 mg/day). The small number of respondents who reported taking caffeine tablets reported a mean caffeine intake from this source of 41 mg/day, though in this case the mean may not be very informative, since all reported

taking several tablets at the same time, to ‘get them through’ a night shift or party, rather than on a regular basis.

Figure 4-1: Overlap, by Percentage of Population, of Weekly Use of Different Caffeinated Beverages



The mean daily consumption of caffeine reported is 357 mg/day (see Table 4-2), which is somewhat above the recommended daily usage of 300 mg/day. In fact, 64% of respondents reported ingesting more than the recommended 300 mg/day.

Table 4-2: Mean Caffeine Consumption, by Caffeine Vehicle, for 168 Respondents, as mg/24 hours

Vehicle	Mean	Standard Deviation	Minimum	Maximum	N
Caffeine mg/24hours	362	292	16	1789	168
Coffee	219	201	13	877	78
Cola/Soda	94	88	6	495	134
Ctg Cola	38	28	11	240	48
Tea	242	173	12	780	116
Chocolate Bars	17	12	4	47	136
Caffeine Tablets	41	25	14	79	10

It may be useful to remember, as a historical note, that at the time the caffeine use survey was carried out coffee shops selling several varieties of brewed coffee (now so ubiquitous) were comparatively rare and not easily accessible either geographically or

financially: 'coffee' was, for this sample, most often of the freeze dried variety, or 'instant' when funds were low. When, in early discussions, students were asked about drinking brewed coffee a consensus emerged that occasionally it was drunk on holiday abroad, after dinner in an expensive restaurant or at home with parents. When a similar discussion was held with police officers, eliciting some mirth, no one was prepared to give an opinion as to the origins of the 'brown liquid that passes for coffee'. A little detective work allowed the researcher to find a cache of empty catering size 'instant' coffee tins of a well known brand and eventually it was confirmed that this was what was poured into the coffee machine. It is generally reported that brewed coffee contains more caffeine than 'instant' coffee, so in any future research it will be important to differentiate carefully what respondents mean by 'coffee' and it may be that caffeine levels in a future survey will be found to be higher than reported here. Interestingly, although increases in the sale of whole beans of coffee and ground coffee are reported by some supermarkets to be increasing, no compensatory fall in freeze dried coffee has been noted.

4.2.3.2. Age of Onset of Caffeine Beverage Use

Mean age of onset of regular use of caffeinated beverages was found to be: cola/soda 6.8 years; tea 12.7 years; coffee 14.6 years; caffeine tablets 17 years. Very few participants professed themselves able to remember when they first started eating chocolate, or drinking chocolate drinks, the majority simply reporting 'very young'.

4.2.3.3. Caffeine Usage and Attribute Variables

Whilst acknowledging that gender is an attribute variable, it is considered of interest to explore whether inferential analysis suggests any statistically significant differences between groups. Table 4-3 illustrates levels of caffeine use by gender and a t test shows no sex differences in caffeine usage per 24 hours [$t(166) = 0.564, p = 0.586$].

However, the well documented correlation between caffeine and nicotine (Kole, Snel and Lorist 1998) was supported ($r = 0.316, p < 0.001$). Approximately one third of the sample described themselves as smokers and two thirds as non-smokers. Since the size of the correlation coefficient is within the range that Cohen describes as 'medium', it was decided to carry out further analysis. An independent t test shows that the smokers reported a significantly higher level of caffeine use per 24 hours [$t(164) = 4.26,$

p<0.001] than the non-smokers. This difference may well be due to the fact that smokers metabolise caffeine more rapidly than do non-smokers. Mean total caffeine intake for smokers was found to be 501 mg/24 hours compared with 300 mg/24 hours for non-smokers.

Table 4-3: Mean and Standard Deviation for Levels of Caffeine Use by Gender

Sex	Mean	Standard Deviation	Minimum	Maximum	N
Male	350	326	9	1789	88
Female	375	250	0	1102	80

4.2.4. Discussion

The three findings of most interest from this British survey of young people, as compared with previous studies of caffeine usage, particularly in relation to potential future reproductive success, are firstly the high daily intake of caffeine, secondly the early onset of regular caffeine beverage use and thirdly the pervasiveness of cola/soda consumption.

The mean daily intake of caffeine of 357 mg/day is very much higher than the 186mg/day found by Hughes and Oliveto in their American sample. This may lend support to the argument that correlating older adults' caffeine consumption with medical problems, when health problems have often engendered a reduction in caffeine intake in later years, may represent false-negative results, as these authors suggest. Alternatively, the difference may simply be one of American versus British culture, since Thompson, Rogers, Hayre and Jones report healthy older adults consuming 353 mg caffeine on a daily basis, which is very close to the level found in the undergraduates sampled in this study. The fact that 42% of the present sample of young men and women are exceeding the recommended daily intake for caffeine raises concerns about their current and future fertility and reproductive prospects, particularly since caffeine's detrimental effect on reproductive success has been shown to be dose-dependent. In addition, there may be long-term general, particularly cardio-vascular, effects on health for these young people if they smoke as well as drink caffeine containing beverages, a commonly observed habit, since there is a medical consensus on the deleterious effects of smoking on health. A further matter of potential concern is the fact that 86% of the sample reported eating chocolate bars on at least a weekly basis.

Although the mean caffeine intake from chocolate may be considered to be negligible at 18 mg/day, in public health terms, the concomitant sugar and saturated fat may not be so trivial.

The age of onset for caffeinated beverage use in the present sample is substantially lower for all categories of beverage than was found by Hughes and Oliveto. In the present British sample, mean age of onset for coffee use was 14.6 years, as compared with 19.4 years in the American sample. Similarly, the mean age for the onset of tea drinking in the British sample was 12.7 years, as opposed to 21.6 years in the Vermont sample. This difference in age of onset of tea drinking may well be due to cultural factors and, given the well documented benefits of the antioxidants contained in tea, may not be of any great importance. However, the dramatic difference between the two samples in age of onset of drinking cola/soda is less easily explained and is potentially an issue of concern. Mean age of onset of drinking cola/soda in the present sample was 6.8 years, whereas Hughes and Oliveto report a mean age of onset of 15.7 years. Pollack and Bright, when commenting on caffeine's effects on children's sleep patterns, suggest that limiting the availability of caffeine to children and young teenagers should be considered.

Caffeine's ability to restore optimal performance is well documented (Koelga 1993; Lorist, Snel and Kok 1994) and has become a pervasive element of 'common knowledge'. It is difficult to judge to what extent general knowledge of caffeine's ability to overcome fatigue may be responsible for the much greater current use of cola/soda found in this U.K. survey (78%), as compared with the 1997 Vermont study (47%). The increase in consumption may simply be due to increasingly sophisticated marketing and advertising. Over the last ten years there has been exponential growth in the sales of 'stimulation' caffeine/taurine/glucuro lactone colas, which the makers' advertisements claim alter subjective experience (e.g. Red Bull 'gives you wings'), in addition to the more usual endorsement of cola/soda by famous sports and popular music stars.

In summary, the current U.K. survey reports mean levels of caffeine usage above the recommended 300 mg/24 hours in both smokers and non-smokers, early onset of caffeine ingestion, especially in relation to cola/soda (under 7 years old) and an

unexpectedly high pervasiveness of caffeine use (99%) in this sample. If these levels of usage were to be found across the U.K., there may be public health implications to be considered, particularly in relation to caffeine's effects on the reproductive success of young adults and the sleep patterns of children. It may be appropriate for the medical profession to offer guidelines on caffeine consumption to adults considering parenthood and to parents of young children.

4.3. Study 2: Personality Correlates of Caffeine Use

The following study examines the correlation between specific behaviours, or aspects of personality, and caffeine use in relation to the specificity hypothesis.

4.3.1. Introduction

Correlations between personality traits and caffeine use have been reported over many years. For example, both Adan (1994) and Mitchell and Redman (1993) report correlations between morning and evening types and levels of caffeine use. However, Mitchell's contention that the negative mood associated with caffeine administration is the result of the disruption of biorhythms is difficult to substantiate: the data could equally well be interpreted as reflecting an increase in levels of neural regulation towards that associated with greater stress due to fatigue. As far as major personality traits such as extroversion and impulsiveness are concerned, the pattern is far from clear, some authors finding effects of caffeine whilst others fail to do so. Studies on anxiety offer a clearer picture, the data suggesting that individuals already prone to anxiety become more anxious when caffeine is ingested, which is what the specificity hypothesis would predict. The rationale for the present study, which considers a potential correlation between personality traits and level of caffeine use, is theoretically based and considered to be a first test of the specificity hypothesis.

Extracting a simple definition of 'personality' from the literature is a somewhat problematic undertaking and there are still many alternative views on how best to pursue the issues involved. However, Baron and Byrne's (1997) definition of personality as being the sum of relatively enduring traits, influencing behaviour across time and situation, is well known and relatively well accepted, though as long ago as 1965 Cattell was arguing that specific situations and specific moods, rather than merely traits, determine behaviour (Cattell 1965). Mischel (1973) has argued that the lack of

consistency of behaviour over different situations throws serious doubt on the validity of the trait concept, though he later moved to a more interactionist position, in which both person variables and situation variables are seen to influence behaviour. Since the value of the present study (and arguably of all studies of personality) is dependent on the validity of the constructs used, a brief consideration of the development of personality theory is given below.

4.3.1.1. Rationale for the Study: Development of Eysenck's Theory of Personality

The personality theories of both Cattell and Eysenck comprise a hierarchical taxonomy, at the bottom of which are specific responses, above those habitual responses, above again second order factors, or traits, such as 'persistence' and uppermost are first order superfactors or personality dimensions, such as 'introversion', 'extraversion' and 'neuroticism'.

Over a period of twenty years Cattell (1957) developed a series of different forms of self-report questionnaires, originally using 4,500 adjectives, which he and his associates reduced through correlation to 180, then to 45 trait descriptors, finally obtaining the 16 traits through factor analysis, which constitute the basis of the Sixteen Personality Factor Questionnaires (16PF). Critics agree on Cattell's thoroughness, that his work is well grounded in theory, that care has been taken when considering sampling variables and that the scales have been carefully factor analysed. However, no one other than Cattell and his associates has been able to find the specified sixteen personality factors (Cooper 1998), to the point where Matthews (1989) suggests abandoning Cattell's primary scales altogether. These problems are further underlined when considering that in 1961 Tupes and Christal, using Cattell's rating scales, seemed to discover five consistent personality traits, which came to be used as the foundation of the Big Five personality theories (e.g. Costa and McCrae 1976). In fact, the work Tupes and Christal carried out was not published until thirty years later (Tupes and Christal 1992), the data previously being available only as part of a US Air Force technical report. When the work was finally published, it revealed a number of disquieting methodological errors. For example, the sample consisted of predominantly young male officers, the raters were inadequately trained and the data collected over a very short period of time (Cooper 1998). Further, Block (1995) argues that the emergence of the 'five factors', which were to play such an important part in subsequent personality theory, is likely to

have been strongly influenced by the kind of idiosyncratic factor analysis utilised by Tupes and Christal. Despite the current wide acceptance of the five-factor model of personality there are still, according to Cooper, substantial problems with the model, uncertainty as to whether the five factors exist empirically and real doubt as to whether the model actually measures what it claims.

Despite the very real differences of opinion in the study and measurement of personality, there is relative agreement on two long-enduring personality dimensions, introversion-extraversion and neuroticism-emotional stability. According to Eysenck and Eysenck (1985), these concepts can be found in the works of Galen and Hippocrates, were used by Kant in the eighteenth century and again in greater depth by Jung in the 1920s. Costa and McCrae (1978), when developing the Big Five theory, found two clear clusters of items, interpreted as 'extraversion' and 'neuroticism' together with a much smaller cluster, these constructs forming the basis of their original theory, to which they later added two further factors.

The two dimensions of introversion-extraversion and neuroticism-stability form the basis of Eysenck's (1952) 'biological' theory of personality. Later, Eysenck added a third dimension, psychoticism. Hence, Eysenck's model is often referred to as the PEN model. These dimensions or superfactors were, according to Eysenck and Eysenck (1985), based on 'constitutional, genetic, or inborn factors, which are to be discovered in the physiological, neurological and biochemical structure of the individual' (pp. 42-43). Specifically, levels of extraversion are seen by Eysenck to be determined by levels of activity in the ascending reticular activating system (ARAS), which is responsible for general arousal and patterns of attention and sleeping, stimulating cortical arousal, such that 'introverts are ... chronically more cortically aroused than extraverts' (p. 197). Neuroticism or emotionality is determined by activation thresholds in the limbic system (including the hippocampus, hypothalamus, amygdala, cingulum and septum), the 'visceral brain,' or SNS and psychoticism is determined by levels of gonadal hormones such as testosterone and enzymes such as monoamine oxidase (MAO). Despite his adherence to the importance of genetic, inborn factors in his theory of personality, Eysenck conceded that responses (physiological or questionnaire) to factors such as introversion and neuroticism could be and were affected by the administration of sedatives and stimulants, that is, a change of internal environment, so could not be

entirely 'fixed'. In later life, in relation to his interest in differences in IQ (which was originally considered a personality factor) and academic performance, Eysenck worked with Schoenthaler (Schoenthaler, Amos, Eysenck, Peritz and Yudkin 1991), documenting the changes that result in IQ and behaviour when children's diets are improved (see also Benton and Roberts 1988; Snowden 1997). It became clear to the author, in conversation with Eysenck in 1994, that these studies provided further evidence to Eysenck that indicators previously considered fixed and inborn are not necessarily so.

Eysenck made a valuable contribution to the study of personality in that he moved the focus of research away from purely descriptive theories to a theory providing empirically testable hypotheses. However, there are a number of widely acknowledged problems with PEN. Eysenck's original theory, which measured only neuroticism (and physical health) through the Maudsley Medical Questionnaire (MMQ) was based on 'inhibition' and derived from an analysis of the responses, in 1947, of 700 male neurotic soldiers, each answering thirty-nine questions. In 1952, a study of psychiatric patients ('hysterics') revealed an additional dimension, 'extraversion' and a new measurement instrument, the Maudsley Personality Inventory (MPI) was developed by Eysenck, which recorded both extraversion and neuroticism. As a result of this study, the theoretical basis of his model changed from 'inhibition' to 'arousal'. Ten years later the Eysenck Personality Inventory (EPI) added a social desirability, or lie scale and finally in 1975, after working with psychopathic individuals, the Eysenck Personality Questionnaire (EPQ) added a psychoticism scale, since his previous scales had been unable to distinguish between schizophrenics, or borderline schizophrenics, and normals. At this point, the three dimensions, or superfactors of PEN were in place: neuroticism, extraversion and psychoticism. However, Eysenck continued to refine his theory of personality, most notably in relation to impulsiveness, which was originally considered an aspect of extraversion but which was later removed from scales measuring extraversion to those measuring psychoticism. The reason Eysenck gave for this change is that, although impulsiveness correlated quite well with extraversion, it correlated 'even better with psychoticism' (Eysenck and Eysenck 1985, p. 69).

In 1981, Gray published a reformulation of Eysenck's model of personality in which impulsiveness and anxiety become the superfactors, extraversion and neuroticism being

demoted to 'secondary consequences of the interactions between impulsivity and anxiety systems' (p. 261). Gray argues (1972) that this model is a better fit to data collected from animal studies and that susceptibility to punishment is related to his concept of anxiety and susceptibility to reward to impulsiveness. The underlying neurological system for impulsiveness, according to Gray, consists of the strength of the behavioural activation system (BAS) and for neuroticism the strength of the behavioural inhibition system (BIS). Consequently, Gray's theory predicts that impulsive individuals will condition more easily with a rewarding unconditioned stimulus and that anxious individuals will learn better from aversive stimuli, which is in clear contrast to Eysenck's contention that the more highly aroused introverts will condition more readily than under-aroused extraverts.

Other authors, for example Depue and Collins (1999) have found correlations between high levels of dopamine with extraversion and that dopamine inhibitors such as MAO are inversely related to extraversion. This is a useful approach, though the number and complexity of even presently known neurotransmitters and their multiple sites of activation, together with the complexities of the behaviours encapsulated within the term 'extraversion', militates against any one-to-one convergence of a specific pattern of known neurotransmitter activity and a set of specific behaviours (subsumed by personality dimensions) at least in the foreseeable future.

There is, then, considerable difference of opinion amongst theorists, even when considering the same personality constructs and an obvious source of clarification would seem to be the empirical evidence offered by authors for their views. However, this is not as straightforward as one might hope. One of the main contentions of PEN theory is that introverts condition more readily than extraverts (hence extraverts are slower to learn and more likely to break society's rules). Eysenck claims to have empirical evidence for this but other researchers have had difficulty replicating his findings. A major problem with using the idea of 'conditionability' as evidence is that individuals do not condition at the same speed across different paradigms (Cooper 1998), so that, if a negative correlation between conditioning time and extraversion is found, as Eysenck claims, in the 'eye puff' paradigm, those same individuals will not necessarily show a similar pattern when being conditioned using a different experimental procedure. Similarly, there are problems in attempting to support

Eysenck's contention that introverts take longer to habituate to the orienting reflex, since both pitch and loudness of the tone affect responses, neither of which is explained by either Eysenck's or Gray's theories. Gale (1983) reviewed 38 studies examining differences in levels of 'arousal' (itself a problematic concept) between introverts and extraverts, concluding that only just over half the studies supported Eysenck's idea of extravert under-arousal. In fact, even when recent studies have found evidence that seems to support Eysenck's theory, further analysis indicates that it is impulsiveness, which Eysenck transferred from the extraversion dimension to the psychoticism dimension, rather than extraversion *per se*, which correlates with time to conditioning or levels of 'arousal'.

There is one test which Eysenck used to support his PEN theory which has been reliably replicated: the 'lemon slice test'. It will be argued here, however, that there is an alternative and arguably more tenable explanation of the data than the interpretation supplied by Eysenck. When asked to hold a slice of lemon in the mouth, it has been found that extraverts salivate more readily and report the task less unpleasant than do introverts. Eysenck interpreted this to mean that 'stimulus hungry', under-aroused extraverts liked and needed strong flavours because of their 'strong' nervous system. The immediate question which springs to mind is why the effect is found with lemon juice and only with lemon juice, since there are many other strong flavours which are not tolerated differentially by introverts and extraverts. PEN has no answer to this question but an alternative interpretation of the 'lemon slice' data is tentatively offered here. For generations before vitamin C was discovered, women living in areas where citrus fruits grow are reported to have sucked on lemons to relieve menstrual cramps, in much the same way that elite athletes now saturate their body cells with vitamin C for days before a race: lemon is a rich source of vitamin C and high levels of vitamin C prolong the release into the bloodstream of calcium from the sarcoplasmic reticulum. The reasons why menstrual women and athletes would benefit from increased calcium in the bloodstream are self evident, but what state of affairs would necessitate a higher requirement for circulating calcium in extraverts but not introverts?

A tentative explanation for this, which may also throw light on some of the other ambiguities in this area of research, is to return to Porges' Polyvagal Theory. If one accepts a continuum of levels of neural activation, or neuroception, from 'safe

environment' (very low arousal to low arousal) to 'potentially unsafe environment' (moderate arousal to high arousal) to 'life threatening environment' (extreme arousal), it is possible to map typical introvert behaviours on to those associated with the monitoring of a largely safe environment, typical extravert behaviours and higher arousal to behaviours associated with a potentially unsafe environment and psychotic behaviours to those associated with the extreme levels of arousal associated with life threatening environments. In such a model, active and lively extraverts are always close to a state of fight or flight: hence the requirement for additional calcium offers a potential, if speculative, explanation for their response to the 'lemon test', since increased calcium results in increased physical endurance to facilitate escape.

This model also offers a potential explanation for the effects of loudness and pitch on conditioning to a tone, where introverts were expected (but failed) to condition more readily. A loud tone, not surprisingly, is generally found to be stressful, so it is likely that individuals considered introverts were moved along the continuum towards the perception of an 'unsafe environment' and concomitant level of arousal, blurring expected differences between introverts and extraverts. This would effectively move 'trait' introverts into a temporary extravert 'state', hence precluding the expected differences in conditioning. Further, the poor performance of extraverts, compared with introverts, on vigilance tasks may be due to the narrowing of attention associated with increased arousal (Velichkovsky 1982), as they sweep the environment with the stress-induced 'search light' of narrowed attention. If there are indeed differences in basal arousal between introverts and extraverts (Eysenck's 'strong' nervous system), the high level of physiological arousal experienced by extraverts may well be sufficient to create the neuroception of threat, sufficient to change their behaviour to fight or flight readiness.

There is a marked division in Eysenck's (1967) theory of traits typically associated with *unstable* extraverts, 'touchy, restless, aggressive, changeable, impulsive, active' as compared with the typical *stable* extravert, who is 'sociable, outgoing, talkative, responsive, easygoing, lively, carefree'. In a neurally regulated model of personality based on Polyvagal Theory, these differences can be accommodated by considering firstly the level of perceived threat in the environment (and hence the individual's position of the 'under stress' continuum), secondly the ease and frequency with which

the individual is able to access the self-soothing behaviours of the vagal brake and thirdly the level of skill available when utilising the primate facility for enhanced communication. It is acknowledged that this reassessment of Eysenck's theories has something in common with Gray's (1981) reformulation, in which the two main dimensions become 'impulsivity', which is high on extraversion, and 'anxiety' which is low on extraversion, both factors being high on 'neuroticism'. Gray, however, developed his theory largely on the basis of animal studies, primarily rodents, whereas the above reformulation is based on Polyvagal Theory in which 'the mammalian nervous system is not only sensitive to environmental demands and perceived stress and threat but ... will, in predictable order, rapidly reorganize to different neural-mediated states' (Porges 2002, p. 10). These reorganizations may incorporate the behavioural switch from 'flight' to 'fight' in unstable extraverts and in stable extraverts the utilization of the additional 'vocalization', the advanced social engagement systems of primates.

It is always difficult to interpret correlational studies but in experimental studies of animals, for instance of caffeine and changed behaviour in mice, Meyer, Caston and Lieberman (2004) suggest that levels of caffeine use do affect behaviour, specifically, that the animals administered caffeine become more wary, less venturesome and exhibit much reduced exploratory and investigative behaviour. In human terms this behavioural change could be interpreted as less extravert and more introvert. Since the specificity hypothesis argues that the documented increased arousal caused by caffeine ingestion shifts levels of neural regulation on the stress continuum from 'safe' to the lower end of 'potentially unsafe', the increase in wariness and more cautious behaviour is to be predicted. This contention is of more than merely theoretical interest since venturesomeness has been linked with traffic violations such as speeding, hit-and-run, violation of right of way and jumping red traffic lights in young male drivers (Renner and Anderle 2000). Their study examined a hundred juvenile traffic offenders (81 male, 17 female) on the personality traits of extraversion, neuroticism, psychoticism, impulsiveness and venturesomeness. The only personality trait to correlate significantly with number of traffic violations is reported to be venturesomeness. Further analysis revealed a significant difference in levels of venturesomeness between traffic offenders and controls in the male sample (analysis of females not being tenable due to low numbers of offenders). This suggests that a better understanding of the concept of

venturesomeness has the potential to save lives on the road. Where individuals find themselves in a situation which creates a state of high arousal and frustration, such as driving in heavy traffic, which the nervous system may interpret as ‘potentially unsafe’, or threatening, caffeine ingestion may well shift perception of stress towards the higher end of the ‘potentially unsafe’ continuum, with consequently more extreme fight-or-flight behaviours, such as is seen in the phenomenon of ‘road rage’.

Since caffeine has been shown in the literature to increase arousal on a range of indicators, this alternative model of behaviour, based on Polyvagal Theory, may be tested initially by correlating levels of caffeine use and measures of venturesomeness. Specifically, it is hypothesised that a significant, negative, relationship between levels of caffeine use and venturesomeness will be found, in a sample of undergraduates. The personality traits of venturesomeness, impulsiveness and empathy are measured by responses to the IVE questionnaire (Eysenck and Eysenck 1991).

4.3.2. Method

The question of a potential relationship between caffeine use level and personality is investigated empirically.

4.3.2.1. Design

The design of this study is correlational.

4.3.2.2. Participants

An *ad hoc* sample of undergraduates reading for social science or computing degrees at B.C.U.C. served as respondents, 88 male and 80 female. With regard to chronotype, 38 participants described themselves as ‘morning’ types and 96 as ‘evening’ types, whilst the remaining respondents did not categorize themselves clearly as either. Age of respondents ranged from 18 years to 37, with a mean age of 29 years. There was no significant difference in age between males and females in the sample.

4.3.2.3. Materials

Caffeine use questionnaire (appendix ii) together with Eysenck and Eysenck’s (1991) IVE questionnaire (appendix iii).

4.3.2.4. Procedure

Respondents (as above) were asked to complete questionnaires about typical daily caffeine use and to fill out a copy of Eysenck's IVE questionnaire. Correlations between scores on the traits of impulsiveness, venturesomeness and empathy with total caffeine ingestion were carried out and are reported below.

4.3.3. Results

With regard to personality variables, contrary to previous findings, there was no relationship between chronotype and caffeine use, although a significant correlation between chronotype and ctg cola ($n = 38$) was found, $r = 0.360$, $p = 0.027$, evening types consuming more ctg cola than morning types. The expected correlations between impulsiveness, venturesomeness and empathy were found but of greater interest is the significant negative correlation between total caffeine use and venturesomeness ($r = -0.157$, $n = 160$, $p < 0.05$), indicating that, in this sample, greater caffeine use is associated with reduced venturesomeness. This supports the hypothesis in relation to the specificity, that is, that the increased arousal produced by caffeine use enhances wariness and reduces venturesomeness, and is in line with the results of comparative studies. In these data no overall relationship between levels of caffeine use and impulsiveness or empathy was found.

When the data set are split by gender (Table 4-4), a different pattern of effects becomes apparent. Both males and females demonstrate the inverse relationship between caffeine use and venturesomeness reported above but, in addition, in females a significant negative correlation ($r = -0.315$, $n = 80$, $p = < 0.01$) between levels of caffeine use and impulsiveness is found. Although levels of caffeine consumption are very similar between males and females, as shown in Table 4-3, at 350 mg for males and 375 mg for females per 24 hours, a comparison of the correlations between caffeine use and impulsiveness and venturesomeness across gender show significant differences, that is, on both behavioural traits males and females differ significantly, whilst the difference between males and females on empathy does not reach statistical significance. As far as impulsiveness is concerned, the difference between males and females on the correlation between caffeine intake and impulsiveness is found to be significant, $Z_{obs} = 2.89$, which is clearly outside the critical boundaries of $Z_{obs} = -1.96$ to 1.96 (Pallant 2001). Similarly, the difference between males and females on the correlation between

caffeine intake and venturesomeness is found to be statistically significant at $z_{obs} = 5.44$. However, as far as empathy is concerned the difference in correlation coefficients across gender of $z_{obs} = 1.195$ is within the critical boundaries and does not reach statistical significance. Caffeine use explains significantly more of the variance in impulsiveness for females than for males, whilst more of the variance in venturesomeness is explained by caffeine for males than for females.

Table 4-4: Mean and Standard Deviation of Caffeine Use (in mg), Impulsiveness, Venturesomeness and Empathy (as measured by the IVE) by Gender

Sex		Mean	Standard Deviation	N
Male	Caffeine	351	326	88
	Impulsiveness	55	9	88
	Venturesomeness	41	10	88
	Empathy	51	9	88
Female	Caffeine	375	251	80
	Impulsiveness	53	10	80
	Venturesomeness	43	11	80
	Empathy	41	8	80

The different patterns of relationship between caffeine and venturesomeness and smoking and venturesomeness are of interest in these data. Whereas caffeine is significantly negatively related to venturesomeness, smoking is significantly positively related to venturesomeness ($r = 0.315$, $n = 158$, $p = <0.001$). This may be interpreted as meaning that while caffeine elicits a feeling of slightly increased anxiety, nicotine elicits an opposite feeling. Conjoint use of caffeine and nicotine has been studied widely, Warburton (1998) reporting that since biochemical data indicates a common neurochemical mechanism of action and the behavioural data shows a common mode of action, a negative association between use of the two substances might be expected, as is found here, ($r = -0.316$, $n = 166$, $p = <0.001$). There is considerable conflict in the literature about the nature of the relationship between caffeine and nicotine use, several studies reporting positive correlations but Pritchard, Robinson, DeBethizy, Davis and Stiles (1995) arguing that a third variable may be influencing both coffee and cigarette use, resulting in an erroneous positive association. More specifically, they state their belief that the often reported epidemiological link between cigarette smoking and coffee

drinking may be non-pharmacological, taste, ritual and alcohol use being suggested as potential mediating variables. Interesting though this debate is, the present thesis confines itself to the behavioural effects of caffeine, the debate about conjoint use of caffeine and nicotine serving only to add weight to the argument put forward in Chapter One that an analysis in terms of neurotransmitter effects is presently untenable.

4.3.4. Discussion

Of particular interest in these data is the significant inverse relationship found between levels of caffeine use and venturesomeness. No causal conclusions may be drawn from correlation but the fact that experiments in animals have demonstrated causality suggests the possibility that causality exists, as predicted by the specificity hypothesis. Caffeine increases arousal on a number of objective and subjective indicators and the specificity hypothesis predicts that increased neuroception of stress, or threat, will shift behaviour from that appropriate in a safe environment to that appropriate in a potentially unsafe environment. As far as venturesomeness, or exploratory behaviour, is concerned, a reduction in such behaviour is likely to be adaptive under increased perceived threat and that is what has been found here, supporting the experimental hypothesis.

As far as the strong negative correlation in females between levels of caffeine use and impulsiveness is concerned, any interpretation can only be speculative, but it is suggested by anthropologists, with regard to recent studies of hunter-gatherers, that females of reproductive age in such groups spend much of their time either pregnant or breastfeeding: in such circumstances the reduced levels of impulsiveness and venturesomeness shown in relation to the neuroception of stress may well be adaptive (and may well have been adaptive to us in our ancestral past). In the present study, although not predicted, the strong negative correlation between caffeine and impulsiveness in females of reproductive age should, in retrospect, have been predicted from the specificity hypothesis, since the change in behaviour is clearly likely to be adaptive.

The non-significant but high level of recorded empathy in males, compared to females, is unusual and contrary to findings in the literature. Again interpretation can only be speculative. It may be that cultural imperatives to be 'new men' have affected the level

of social desirability expressed by males in their responses to the questionnaire, or it may be that, despite research to the contrary, men in general are more empathic than females, or alternatively it may be due to differences in the samples of males and females. The female student respondents were predominately studying Criminology or Psychology whereas the male students were studying either Policing or Computer Studies. It may be that the kind of young man who wishes to become a police officer is more interested in people and society (and hence more empathic) than the average male of his age. Alternatively, a large proportion of this sample of computing students are known to be Muslim. Both the Bible and the Qu'oran advocate empathy and compassion, but in this particular sample there may have been more devout Muslims than devout Christians present. In retrospect it is considered that any study examining habitual behaviour or personality traits should take cultural background and religious beliefs into account, since otherwise there is the chance that these elements may serve as confounding variables. Clearly this is a valid criticism of the present study, which future studies need to take account of.

4.4. General Discussion and Conclusions

Study 1 has revealed caffeine use in young people of reproductive age to exceed the medical guidelines and to be far in excess of that associated with reduced fertility and reduced fecundity. These levels appear to be sufficiently high to represent potential harm to surviving offspring. It became apparent through discussion that neither males nor females were aware of these potential effects and it is recommended that health authorities give thought to ways of increasing the dissemination of the known negative effects of caffeine on reproductive success. The relatively high usage found lends weight to the argument that an overall theory of the behavioural effects of caffeine is long overdue, the specificity hypothesis with its neuroanatomical grounding and predictable behavioural consequences, attempts to extend current understanding.

In study 2, the negative correlation found between venturesomeness and caffeine supports the prediction made from the specificity hypothesis and, in addition to theoretical interest, offers a potential explanation for the findings of Renner and Anderle. As far as the habitual responses which underlie personality theory are concerned, the increased neuroception of arousal indices and behavioural change caused by caffeine ingestion may be seen to offer some support for Gray's notion of BIS and

BAS in his reformulation of Eysenck's personality factors. According to Gray, individuals with high levels of impulsiveness are highly sensitive to reward and non-punishment (BAS), whilst highly anxious individuals are highly sensitive to punishment and non-reward (BIS), extraversion being the consequence of the relative strengths of these two systems. It is not seen as appropriate to rehearse the criticisms of Gray's theory, which have been levelled by other personality theorists, here though it is conceded that the lack of empirical evidence for Gray's ideas is troublesome. Considering Renner and Anderle's (2000) study of juvenile traffic offenders as an example of relevant empirical data, Gray's theory would predict a positive correlation between number of offences and impulsiveness and a negative correlation between number of offences and anxiety: in fact the only correlation found was with venturesomeness, which the specificity hypothesis predicts. From the perspective of behaviour as the result of constantly changing patterns of neural regulation, in response to subtle differences in the internal and external environment as Polyvagal Theory and the specificity hypothesis predict, Gray's theory may appear a little static.

To some extent, a perspective on personality through the specificity hypothesis offers a degree of reconciliation between extreme 'trait' and extreme 'situationist' theories. Mischel (1968), a social learning theorist, reviewed a large number of studies and concluded that scores on personality tests and measures of behaviour in various different situations rarely exceeded 0.3, a finding which led him to reject the trait approach and develop the theory of situationism, that is that behaviour is largely determined by situational factors. Other authors, such as Bowers (1973) have argued that creating a dichotomy between situational factors and personality traits is to oversimplify a complex issue. After examining aggression in boys, anxiety in students and deferred gratification in children Bowers concluded that 13% of variance in behaviour is due to person variables, 10 per cent to situational variables and 20% to an interaction between the two. This is very much in line with what an examination of personality through an perspective of specificity predicts: basal differences in levels of arousal between introverts and extraverts become blurred when introverts are exposed to perceived stress and extraverts to perceived safety, behaviour being an interaction of basal arousal and the neuroception of environmental stress.

However, although study 2 would seem to offer tentative support for the specificity hypothesis, both the studies presented so far are correlational and so speculative and *post hoc*: hence the specificity hypothesis is next tested experimentally against Lorist's existing model of the behavioural effects of caffeine by experimental studies.

Chapter Five

Evaluation of Lorist's Contention that Caffeine Affects Only Input and Output Processes

5.1. General Introduction

This chapter attempts an evaluation of Lorist's model of caffeine's effects on human information processing (HIP), as exemplified in her diagram, (Figure 1-1). Although much credit is due to Lorist for developing a model of caffeine's effects on information processing, there are a number of issues relating to the model which need to be addressed. For example, there may be difficulties with the serial processing, structural model of cognition Lorist has chosen to utilise and with her attempts to interpret or bind specific aspects of cognitive processing to specific event-related brain potentials (ERPs). This is perhaps not surprising, since current thinking in this area is that 'cognitive architecture is far too complex for any complete, detailed model [of cognition] to be developed in the near future' (Matthews, Davies, Westerman and Stammers 2000 p. 65).

An attempt is made to evaluate Lorist's findings by carrying out experiments similar to those she has carried out: similar, in that the same structural task elements are available to demonstrate the effects of caffeine, as posited by Lorist's model, but these elements are embedded within alternative tasks. The experiments all test responses to visual choice, as do the experiments from which Lorist derives her model. Lorist's contention that caffeine affects input and output processes will also be explored since, although the notion is clearly supported within the visual choice tasks used by Lorist, she offers no rationale for why caffeine affects input and output processes in some tasks but not in others.

There are, in the research record, other types of behaviour where caffeine's effects are differential depending on the specific elements of the task. For example, in sport caffeine improves performance in activities such as running, cycling and skiing, where distance is covered, but does not confer any advantage in activities such as weight-lifting. Through the perspective of evolutionary psychology, and specifically through the framework of the specificity hypothesis, increased speed and endurance in covering distance (away from a perceived threat) is seen as potentially adaptive behaviour,

whereas lifting heavier weights is not. This raises the question of whether, in relation to information processing, caffeine's effects may accrue to those processes where improved performance provides potential adaptive benefit. Three experiments are reported in this chapter, in an attempt to disambiguate caffeine's effects on the input, output and central processing aspects of performance: experiments which examine caffeine's effects on different card sorts, on speed of verbal and numerical processing and on local and global processing.

5.1.1. Lorist's Model of Caffeine and Human Information Processing: an Overview

Lorist, Snel and Kok (1994) report, as a result of their studies of caffeine's effects on visual choice reaction time, that caffeine facilitates the input-perceptual (feature extraction) and output-motor (response preparatory) components, whilst failing to affect central (response choice) components, of the tasks used. The processing stage model of cognition maps very nicely on to Lorist's model (Figure 1-1) but, unfortunately, there is a considerable body of research which remains unaccounted for by this analysis, for example, caffeine's effects on the Stroop task (Foreman, Barraclough, Moore, Mehta and Madon 1989), on visual grid tasks (Coren 2002) and, most compellingly, on the many instances of apparently similar cognitive tasks yielding contradictory findings, as detailed in Chapter Two. In addition, there does seem to be some doubt as to how useful it is to compartmentalize aspects of performance in this structural way.

A full account of mental function is not presently within reach but general theoretical models of how cognition may be organised and models of specific subsystems, such as selective attention or short term memory, have been developed. A comprehensive example of the former is offered by Wickens (1992), whose model starts with sensory processing of the stimulus, where iconic and echoic properties are stored in a rapidly decaying short term sensory store and then passed to later stages of perception, where the stimulus is identified or categorised in terms of its personal significance. Following this, the information is passed to decision and response selection processes, which are referred to as central processes, where response is guided by knowledge and experience from long-term memory and potential actions and consequences 'debated' in working memory. Finally a decision is made and a response selected, leading to execution of the appropriate motor actions. The system is in dynamic interaction with the external world and the speed and accuracy of the component processes depend on sufficient allocation

of attentional resources, together with feedback signals. From the perspective of evolutionary psychology and the specificity hypothesis, an important element of the above model is the categorization of the stimulus *in terms of its personal significance*. Hence this model is in clear contrast to serial processing, stage models, which are considered to be passive, information being fed from one stage to the next, with little active involvement of the individual, such as the model put forward by Lorist.

An exception to the absolute passivity of many stage models is that of Sanders (1983), whose work Lorist used for the development of her model. In Sanders' model, information flow is bottom-up and serial but includes three 'arousal mechanisms' that influence different stages of processing: motor adjustment is affected by an activation mechanism, an evaluation mechanism responds to feedback and an additional mechanism acts to maintain optimal arousal. These three elements may be seen in Lorist's model, described as 'arousal', 'effort' and 'activation', which she has mapped on to different neurotransmitter systems. However, as Massaro and Cowan (1993) have argued, there are uncertainties as to whether representational codes (such as feature extraction) at each stage are discrete or continuous, whether processing at any stage is single-step or continuous and whether transmission of information from step to step is discrete or continuous, which pose substantial problems for Lorist's model. In addition, insufficient detail of the three putative arousal mechanisms is given. The mechanism that is described as maintaining optimal arousal is of particular interest: it would be useful to know in which circumstances it is effective, in which circumstances (if any) it fails, how arousal is initiated and how it is maintained.

In addition, Rabbitt (2008) argues that processing stage models are unable to account adequately for speed-accuracy trade-off data. Where, as in these models, there are multiple stages, it is plausible to assume that each stage may have its own particular speed-accuracy trade-off characteristic (i.e. that not all stages have the same speed-accuracy function) but implausible to assume that individuals have access to this information: hence when participants are asked to favour speed over accuracy (or vice versa) they must be exercising control over the whole task (which would involve making differential adjustments at each stage of processing). If this is the case then stages must be independent, which violates a basic assumption of stage models. Rabbitt (1989), having worked in the area of speeded response tasks for many years, concludes,

We have to assume dynamic, active, *adaptive* [emphasis added] control of a number of interlocked systems all of which, acting together, must adjust to any change in task characteristics (p. 168).

Stage models appear unable to do this, whereas a parallel distributed processing (PDP) or connectionist model may theoretically do so. In our present state of limited knowledge of the precise mechanisms underpinning cognition and human information processing, it is argued that it is not currently possible to posit specific effects of caffeine on particular sub-processes. The focus of the present thesis therefore, as opposed to Lorist's, is on which types of tasks and in which environments the effects of caffeine ingestion are reliably seen.

Lorist (1995) herself concedes, citing Miller (1988) and Smid (1993), that 'In fact, experimental evidence suggests that information might undergo continuous transformation, with an overlap in time between different processing stages' (p. 5). She moderates her position further by adding that 'caffeine affects output-related processes taking place after the start of response preparation' (Lorist 1998 p. 199), a statement which requires alteration to the original model. Lorist does not indicate how long 'after' the start of response preparation caffeine's effects occur or whether this delay is constant over different cognitive tasks. If information does undergo continuous transformation, as suggested by PDP models of cognitive functioning, then a stage model such as Lorist's may no longer be appropriate.

It seems that, even within the constraints of caffeine's effects on visual choice reaction time (VCR), Lorist's model is not able to account for all relevant empirical data. In reviewing a substantial number of experiments assessing caffeine's effects on simple reaction time (SRT) and choice reaction time (CRT), utilizing visual or auditory stimuli, Van der Stelt and Snel (1998) report that only in about half the experiments was RT reduced, whilst accuracy was sometimes improved and sometimes unaffected. In attempting to account for the 50% of these studies where caffeine was not found to have an effect, the authors cite Lieberman (1992), who identified differences in caffeine dose, protocol, task and attribute variables as plausible reasons for the discrepancies found in experimental results. An additional argument, first put forward by Welford (1968) and

supported by Van der Stelt and Snel, is that such studies fail to distinguish between the motor and decision components of the task. This conclusion appears to have been the impetus for Lorist's model of input, output and central processing, which in its original form argued that central processing is entirely unaffected by caffeine.

5.1.2. Empirical Studies Examining Input/Output Processes

The tasks chosen for the present study are designed to test Lorist's argument that input/output, but not central processing, is affected by caffeine. In addition, the thesis addresses the question of why the input/output processes of some tasks but not others appear not to be affected by caffeine. Although Lorist's model holds much merit, it is argued that an evolutionary perspective, such as drives the specificity hypothesis, is able to offer further clarification of the mechanisms underlying behavioural change under caffeine ingestion.

In all tasks participants are faced with novel stimuli, about which they must make a simple choice. One possible theoretical cause for the differential effects of caffeine may be that tasks providing novel stimuli which are participant controlled will not be interpreted by the nervous system as an added threat, whereas novel stimuli generated externally (i.e. computer generated) will be seen as a potentially more threatening change to the environment. Both types of task are examined in this chapter. Alternatively it may be the nature of the task *per se*, which elicits change in performance under caffeine ingestion. It may be that what is critical is not merely the structural elements and sub-processes of the task but rather the task's 'personal significance', as posited by Wickens, personal significance being exemplified here as any potential threat to survival. On this basis, if improved performance on a behaviour has the potential to be adaptive, the increased arousal and wariness induced by caffeine may plausibly trigger the survival response and an effect of caffeine on performance will be seen. It appears from the research record that input/output processes, whether visual or auditory, are not of themselves necessarily susceptible to the effects of caffeine.

As far as the empirical research studies reported in this chapter are concerned, three alternative explanatory possibilities of which task elements elicit caffeine's effects on behaviour are considered and evaluated: firstly, that control over novel stimuli is the

critical factor; secondly that it may be the nature of a specific cognitive process that is critical; thirdly that it may be the level of perceived personal significance that proves to be the critical factor. These potential strands of causality are not mutually exclusive but it is hoped that the following experiments will clarify the effects of these elements.

Since experiments 1 and 2 relate to the same participants (serving police officers) and are carried out in the field, whereas experiment 3 is carried out under controlled laboratory conditions and utilizes a different sample (undergraduates), the first two experiments are written up together, followed by experiment 3.

5.2. Experiment 1 (Card Sorting) and Experiment 2 (Verbal and Numerical Processing Speed)

Experiments 1 and 2 address the issues of input, output and central control in Lorist's model.

5.2.1. Introduction and Rationale

The card sorting protocol, utilized by Loke, Hinrichs and Ghoneim (1985) is designed specifically to distinguish between the motor process of sorting playing cards into two different piles and the perceptual and decision processes of allocating a card to a particular category, such as black/red, odd/even or median split. It is assumed that the motor components, together with extraction and stimulus identification processes (input/output processes), of the card sorting tasks remain the same across tasks and consequently any differences in time across the three sorts will reflect differences, in Lorist's terms, of central processing. Any differences across caffeine conditions will consequently reflect caffeine's effects on those central processes. More specifically, in relation to Lorist's model, the identification process involved in the first sort (black/red) is relatively simple and perceptually based and, since it relates to Lorist's input stage, may be expected to be susceptible to caffeine's effect. On the other hand, the median split, together with the odd/even sort (which involves allocating Jack, Queen and King to 'odd' and 'even') may be more complex decision tasks, involving match to memory, 'serial comparison' and 'binary decision', which are seen as components of central processing in Lorist's model. Accordingly, any differences in RT between caffeine conditions in the median split or odd/even sorts may be attributed to central rather than input/output processes. The verbal and numerical processing tasks again clearly involve

central processing, so are used to evaluate Lorist's contention that central processes are immune to the effects of caffeine.

The above expectations are derived from Lorist's model. However, from the perspective of evolutionary psychology and the specificity of caffeine's effects a different set of hypotheses are formulated, based on the *salience to increased survival chances* of the cognitive processes relating to each task. Since survival relies on the constant monitoring of the environment for potential attack and it has been argued that caffeine increases the neuroception of potential danger through increased levels of arousal, it is plausible to argue that survival orientated cognitive processes may show the effects of caffeine, where non-survival orientated behaviours will not. Insofar as it is possible to separate out cognitive processes, from the point of view of survival, the process of identifying that 'something is there', that is, separating figure from ground, is presumably paramount. Lorist's model, where the first stage is 'feature extraction' does not include this process (figure-ground separation is not discussed further here but is tested for the effects of caffeine ingestion in Chapter Six).

Arguably the next most important process, having perceived that *something* is there, is to identify *what* is there, that is, categorising the new stimulus (subsuming feature extraction and identification) as in 'friend or foe', 'male or female' et cetera. It is acknowledged that these two processes of figure-ground separation and categorisation are not discrete and that many experiments attest to the fact that items are readily identifiable, even when the stimulus is heavily degraded. However, the fact that humans are able to identify objects and make categorisations on minimal information (Biederman 1987) lends weight to the notion that categorisation is critical to cognition and, potentially, to survival chances. The process of categorisation underpins knowledge representation at all times but it is argued here that, under potential threat, accurate processing of novel stimuli into basic categories has adaptive value and hence is predicted to be enhanced by the ingestion of caffeine. This contention is supported by the fact that caffeine causes humans and animals to extend the orienting reflex, that is to 'look longer' at novel stimuli, arguably to allow sufficient processing time to ensure that a novel stimulus is categorised accurately and does not have the potential to compromise safety.

With regard to the three card sorts, from the perspective of the specificity hypothesis, it is hypothesised that the median split does not represent sorting into basic categories and so will not show the effects of caffeine. It is suggested that the black/red sort, being primarily based on processes relating to the discrimination of hue, again cannot be considered dependent on basic categorisation (since in the natural world there many shades of 'red' and 'black'). In addition, there is evidence that under stress colour images lose saturation and become shades of grey (Wright and McKenzie 1996). The odd/even sort, however, may be considered an example of separation into two basic categories and so may show the effects of caffeine. It is important to note that what is being argued here is not that the concept of odd/even has any particular salience, but rather that accurate performance on the underlying process of simple categorisation has adaptive value; it is in fact the same process underlying many of Lorist's studies of caffeine and visual choice.

The verbal and numerical processing tasks are considered somewhat more cognitively demanding than Lorist's visual choice tasks since, in addition to stimulus identification and serial comparison of particular items, in order to locate the target item as 'first' in either alphabetical order or 'highest' in numerical ascendancy, both tasks require searching through memory and comparison with many alternatives. The verbal task requires a decision as to which of three words should be placed first when ordered alphabetically and the numerical processing task a decision as to which of five numbers is the largest. Since the integers contain a median of two digits, whilst the words contain a median of four letters, according to serial processing models such as Lorist's, it is reasonable to assume that the numerical processing will be faster than the verbal processing and, since both relate to central processing, that neither will be affected by caffeine.

In order to test Lorist's premise that caffeine affects input and output process, whilst not affecting central processing, the following hypotheses will be addressed:

- Hypothesis 1: There will be a significant difference in response times, between caffeine conditions, to the odd/even card sort.
- Hypothesis 2: There will be a significant difference in response times, between caffeine conditions, to the black/red card sort.

- Hypothesis 3: There will be a significant difference in response times, between caffeine conditions, to the median split card sort.
- Hypothesis 4: There will be a significant difference in number of items completed, between caffeine conditions, in the numerical processing task.
- Hypothesis 5: There will be a significant difference in number of items completed, between caffeine conditions, in the verbal processing task

5.2.2. Method

5.2.2.1. Design

A mixed (between-within) subject, single blind design is used in both experiments. The between subject independent variable is the presence or absence of caffeine in the cola ingested. The within subject factor in experiment 1 is type of card sort and in experiment 2 is type of processing (numerical or verbal). The dependent variable in experiment 1 is the response time, measured by stopwatch, to complete each of the three card sorts. The number of items completed in the verbal and numerical processing tasks constitutes the dependent variable for experiment 2.

5.2.2.2. Participants

An *ad hoc* sample of 40 male serving police or administrative officers of the Metropolitan Police acted as participants. All had normal or corrected-to-normal vision. Their ages ranged from twenty to forty-eight, with a mean age of thirty-four years.

5.2.2.3. Materials

Both experiments: cans of high caffeine (124mg caffeine) cola (experimental condition) and decaffeinated cola (control condition). Experiment 1: two packs of normal playing cards and a stopwatch. Experiment 2: Power and Performance Measures comprise a battery of nine aptitude and ability tests that measure both ‘power’, that is, reasoning skills that are presumed stable over time and actual performance and ability. In the present instance verbal processing performance is assessed. The British Abilities Scales (numerical processing) is a similarly well established and well regarded test instrument. Construct validity and reliability (in excess of 0.7) is good for both sets of tests.

5.2.2.4. Procedure

Data were collected from the offices of the Metropolitan Police, during normal shifts, over three days. Participants were allocated randomly to caffeine conditions, twenty to each condition, and asked to confirm that they had abstained from ingesting caffeine for the previous three hours. Participants were then administered blindly a can of either high caffeine (124 mg) or decaffeinated cola. Twenty minutes later, the card sorts (sort a double pack of cards into two piles of black/red, odd/even and median split) were administered, the order of sorts being counterbalanced. Each card sort was timed by stopwatch and these times constituted the dependent variable. Immediately afterwards, the verbal or numerical processing tasks were administered, in alternating order. In the verbal task, participants were shown lists of three words and asked to strike through the one which would come first if they were arranged alphabetically. In the numerical task, participants were shown rows of five numbers and asked to strike through the highest number in every line. In both processing tasks, the number of items completed constituted the dependent variable. Examples of the processing tasks may be found in appendices iv and v.

5.2.3. Results

Descriptive statistics were calculated, together with a mixed analysis of variance for both card sorts and processing tasks separately. Normality, linearity, homogeneity of variance-covariance matrices, and outliers were checked, with no serious violations found, before the analyses of variance were computed.

5.2.3.1. Card Sorting

An inspection of the means and standard deviations for each sort by caffeine condition (Table 5-1) reveals that overall the black/red sort was carried out fastest and the odd/even sort most slowly, whereas the times for the median split sort show the highest standard deviation. Further inspection indicates that in both the odd/even and median split sort the high caffeine group was approximately ten seconds faster than the decaffeinated group.

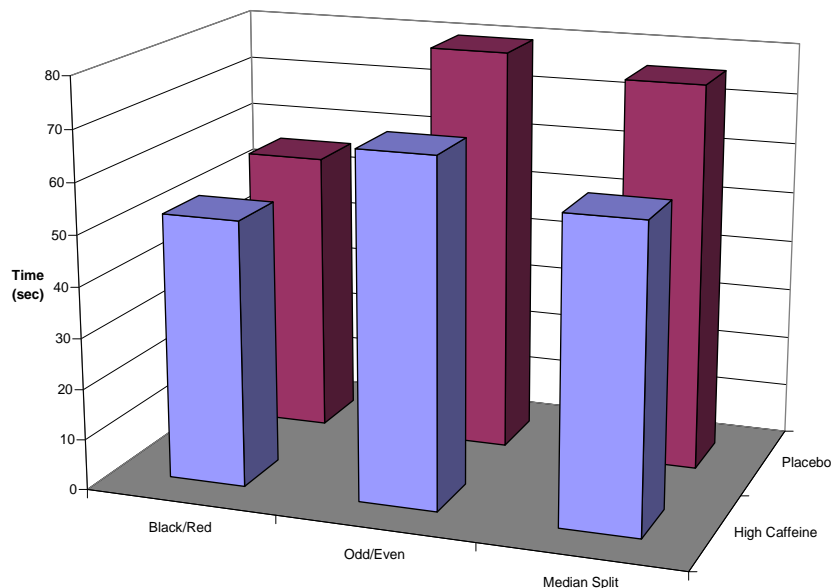
The differences across the card sorts, between experimental and placebo conditions, are further demonstrated by Figure 5-1.

A one-way mixed analysis of variance was applied to the card sort data. Since number of participants is small and caffeine conditions unequal, the significance level of Pillai's Trace is inspected and found to be $p = 0.031$, indicating that there is a statistically significant difference in overall performance of the combined card sorts according to caffeine condition, Pillai's Trace = 0.285. Before continuing with inspections of the effects of caffeine on individual card sorts, it is considered appropriate to apply a Bonferroni post hoc adjustment to the acceptable level of probability, in order to reduce the chances of making a Type 1 error, which results in a new alpha level of 0.017.

Table 5-1: Mean and Standard Deviation (in seconds) for Card Sort Tasks

Card Sort	Type of Cola	Mean	Standard Deviation	N
Black/Red	High Caffeine	52.33	6.51	12
	Decaffeinated	55.67	10.30	18
	Total	54.33	9.06	30
Odd/Even	High Caffeine	67.83	9.60	12
	Decaffeinated	79.67	13.28	18
	Total	74.93	13.15	30
Median Split	High Caffeine	59.33	6.60	12
	Decaffeinated	76.00	15.97	18
	Total	63.93	13.44	30

Figure 5-1: Differences in Scores (in seconds) on Card Sorts Between Experimental and Placebo Conditions



With the new probability level, a significant difference according to caffeine condition is found only in the odd/even card sort, the high caffeine condition being significantly faster than the decaffeinated condition [$F(1,28) = 7.040, p = 0.013$]. Partial eta squared indicates that that 20% of the variance in speed in the odd/even sort is attributable to caffeine's effects, whereas only 8% and 3%, respectively, of variance in the median split and black/red sorts may be attributed to caffeine's effects. Accordingly hypothesis 1, that there will be a significant difference in response time across caffeine conditions to the odd/even card sort is retained, whilst hypotheses 2 and 3 are rejected.

5.2.3.2. Speed of Processing

There is very little difference either in the mean number of verbal and numerical items completed or in the standard deviations, between caffeine conditions, as can be seen in Table 5-2, although it is noticeable that twice as many numerical as verbal items were completed. This, plausibly, reflects differences in the complexity of the two tasks, the numerical task being found easier.

Table 5-2: Mean and Standard Deviation for Number of Items Completed in Processing Tasks in Two Minutes

Processing	Type of Cola	Mean	Standard Deviation	N
Verbal Processing	High caffeine	20.50	5.65	12
	Decaffeinated	24.00	6.93	16
	Total	22.50	6.54	28
Numerical Processing	High caffeine	51.00	6.61	12
	Decaffeinated	50.13	8.30	16
	Total	50.50	7.50	28

A mixed analysis of variance reveals no significant differences in verbal or numerical processing speed across caffeine conditions. Although no significant difference is found between caffeine conditions, the values of partial eta squared suggest that 7.3% (power $\beta = 0.62$) of the variance in verbal processing scores may be attributed to the effects of caffeine, whereas only 0.03% (power $\beta = 0.18$) of the variance in numerical processing may be so attributed. Judicious increase in the power of the experiments, for example by doubling the sample size, would likely show a medium effect of caffeine on verbal

processing, whereas the effect of caffeine on this type of simple numerical processing would likely remain trivial.

5.2.4. Discussion

Experiments 1 and 2 were chosen in an attempt to examine whether new research data would support Lorist's model of caffeine's effects on human information processing. Although different from the tasks used by Lorist in the development of her model, processing speed and card sorting have, arguably, the potential to confirm or disconfirm her theory. In fact, the card sorting experiment suggests that Lorist's conclusion that caffeine affects input and output processes is only partially correct and so must be considered an insufficient explanation of the effects found. Since the same playing cards were used in all three tasks, it must be assumed that the input processes of feature extraction and stimulus identification are identical across all sorts, as is the motor response and actions involved in physically sorting the cards into two piles. Consequently any significant differences in time between the three sorts across caffeine groups must be due to the effects of caffeine on central processing time. In the odd/even sort there is a mean, statistically significant, difference of almost 12 seconds between the high caffeine and decaffeinated conditions, for which Lorist's model is unable to account.

Any attempt to explain this difference, at this time, is inevitably speculative. However, it seems clear that the notion of 'control' of novelty can be discounted, since all card sorts were under the direct control of the participant. As regards the notions of allocation into basic categories and personal significance, it is plausible to assume that these two notions are intimately linked and not mutually exclusive. It is tempting to assume that categorisation must occur first, since a stimulus must be categorised before its personal significance can be assessed, though in reality it seems likely that there may be a considerable degree of overlap between the two (presumably PDP derived) processes. We have all jumped at our own shadows, which suggests that sometimes emotional salience supersedes full processing of stimulus information and that categorization is sometimes made on incomplete information. This is easier to explain from an evolutionarily adaptive perspective, where the cost of not responding to a potential threat may be death, than from a purely cognitive analysis.

In real life situations, potential threat holds considerable emotional salience, especially in situations of perceived danger, so that the probability of mis-categorisation, and responding before full information is available, is a real possibility. Sadly, there are a number of tragic examples of this process, outside the confines of the research situation, usually within very threatening contexts, such as war or potential terrorism. One such case is that of a man, perceived to be carrying a long barrelled gun in a blue plastic bag, who was shot dead in 1999 by the authorities, but later found to be carrying nothing more threatening than a table leg (*Guardian* 3rd June, 2005). In addition, examples of 'friendly fire' have been reported regularly since World War I. Such incidents serve to confirm the importance of both accurate categorisation and accurate assessment of emotional salience.

As far as alphanumeric speed of processing is concerned, neither verbal nor numerical processing was significantly affected by caffeine, though clearly both tasks involve both input and output processes, as well as central processing. Following Lorist's model, one might have expected partial eta squared to reveal that the intuitively simpler numerical task, of indicating which one of five, two digit, numbers was the highest, would show a higher effect of caffeine than the task of deciding which of three words should come first alphabetically, since the former may involve fewer (central processing) comparison steps. However the reverse is the case, eta squared indicating that 7.3% of variance in the verbal task is attributable to caffeine whilst only 0.03% of variance in numerical processing is due to caffeine's effects. It is not clear whether either the additional load in working memory, or the additional number of comparison steps, or both, in the arguably more complex verbal processing task, has made the verbal task marginally more sensitive than the numerical task to caffeine's effects. Alternatively it is possible to speculate that the increased neuroception of arousal, under caffeine ingestion, has promoted neural regulation and reorganisation towards the facilitation of communication, as both Polyvagal Theory and the specificity hypothesis argue occurs in primates under stress. In this case, since it is easier for most humans to communicate in words rather than with numbers, caffeine might be expected to facilitate verbal but not numerical processing. This latter contention, which would support the specificity hypothesis, might be better tested through a paradigm that is more truly 'verbal', that is, where participants communicate with speech, rather than putting written words into alphabetical order.

5.2.4.1. Strengths and Limitations of the Study

A limitation of the study is the nature of the participants who were an all male sample from a particular occupational group, so it is not possible to generalise the findings to females and caution is needed if extrapolating findings to other occupational groups. A further limitation is the use of a manual stopwatch, with the inevitable potential for human error. In addition, reliance on the honesty of participants as to whether they had abstained from caffeine ingestion prior to the study is a further limitation. On the other hand, a strength of the study is that it was conducted in a real world setting, which offers greater ecological validity than a laboratory study. In their everyday work these police officers often made notes on paper in pen or ink, consulting their watches as they did so.

5.2.5. Conclusions and Theoretical Implications

It is argued that the stage, (input, central and output) serial processing model of caffeine's effects is unable to account fully for the present card sort findings, as it has been unable to account for much previous research data. If a model with predictive validity is to be developed, it seems that a different theoretical approach to caffeine's effects on behaviour is necessary. When considering causality in the data described in this chapter, the notion of participant control versus external (computer generated) control has been shown to be false. However, the notion of basic categorisation being affected by caffeine ingestion is supported and seen to have explanatory power within the framework of the specificity hypothesis and is explored further in this chapter within the framework of local and global processing.

As far as the verbal and numerical processing tasks are concerned, Lorist's contention that central processing is not affected by caffeine is largely upheld. However, there are a number of plausible explanations for the non-significant differential effects of caffeine on these tasks. For example, questions related to cognitive load are raised: reaching a decision as to which of three words should be presented first in an alphabetical arrangement is likely to involve more comparison processes and a greater demand on working memory than making a decision as to which of five, dissimilar, numbers is the greatest. In retrospect, these two tasks may be too dissimilar to be especially useful in the present context of attempting to disambiguate caffeine's effects on information

processing. On the other hand, it may not be the cognitive load *per se* that has created the difference of effect, but rather the emotional stress generated by facing one task perceived as more demanding than the other, in which case the more stressful task would be expected to show an effect of caffeine. In the present case, this would mean that the verbal task had been perceived as more stressful than the numerical task, which is counter-intuitive since numerical tasks are generally perceived as more stressful than verbal tasks. At present, any attempt to interpret the verbal and numerical processing data, beyond the lack of a significant effect of caffeine, is merely speculative, though the 7% of variance attributed to caffeine by eta squared may be indicative of a potential facilitative effect on language.

Although experiments 1 and 2 have generated useful data and ideas, there are a number of ways in which their execution may be improved. The attraction of field over laboratory data collection is the promise of greater ecological validity and the opportunity of collecting data in a working police station is very much appreciated. However, in this case, the practical necessity of officers responding to the demands of their profession, which included being called away for periods varying from five minutes to a whole shift, resulted in a much reduced number of participants and in an unequal number across caffeine conditions. This, together with the inability to control background noise, such as mobile telephones, is considered too high a price to pay for any ecological validity that might have been gained. However, there is no evidence to suggest that any of these extraneous variables constituted confounding variables. In addition, in the environment of a custody suite, it was necessary to time tasks in seconds using a manually operated stopwatch, a system which is very much less accurate than the thousandths of seconds usually recorded when tasks are computerized. These less than ideal conditions were spread across caffeine conditions and tasks, so it is not considered that they detract from the significant difference ($p = 0.013$) found between caffeine conditions on the odd/even card sort. However, future experiments will be carried out under more controlled conditions in a laboratory, using computer timing where possible, as in the experiment examining global and local processing, which is described in experiment 3.

5.3. Experiment 3 (Local and Global Categorization)

It is assumed that the processes underlying the categorization tasks applied to local and global stimuli utilise similar sub-processes to those inferred by Lorist. Hence caffeine affecting the two classes of stimuli differentially would raise a further problem for Lorist's model, a hypothesis which is tested below.

5.3.1. Introduction and Rationale

Data from the card sort and information processing tasks described above suggest that caffeine's effects on performance are elicited in simple categorisation tasks. The research record, however, indicates that not all categorisation tasks show effects of caffeine at all times (whereas the orienting response is reliably affected by caffeine) and it is suggested that the task of distinguishing between local and global stimuli may help clarify the position further in relation to caffeine's effects on categorisation, on the basis that local stimuli, under caffeine ingestion, may be perceived as 'near' and worthy of thorough investigation, whereas global stimuli may be perceived as 'distant' generating a lower imperative for investigation, even though in actuality both kinds of stimuli appear on a computer screen at the same time.

In this experimental paradigm, hierarchical or nested letter stimuli are presented via a computer screen where, for example, a physically large, uppercase, 'H' (the global level) may be composed of physically smaller, uppercase 'H's or 'S's (the local level). Participants are required to respond at either the global or local level by pressing a particular key on a keyboard. In some trials the global and local levels are congruent, whilst in other trials they conflict (e.g. a large 'H' made up of small 'S's). Since participants may be asked to respond at either the global or local level to any given presentation of the stimulus and stimuli are repeated many times over, it is plausible to assume, through Lorist's model, that input and output processing requirements are the same for responding to either the global or local pattern throughout a bloc of trials. However, as Navon (1977) demonstrated in his seminal study 'Forest before trees', the global configuration, or holistic shape, is responded to significantly more quickly than the component parts, or features, of the local level stimulus. In effect, we see the forest before being able to distinguish individual trees.

Navon's findings have been replicated many times, demonstrating that generally individuals first process the overall shape of objects rather than individual features. It is difficult to account for this in Lorist's model, since the first step of her model is labelled 'feature extraction' and no account of holistic processing is given. Differences in RT to global and local processing (with or without increased arousal) are presumably in Lorist's terms due to central processing, such as serial comparison, rather than input and output processing. It is therefore of interest to ascertain whether the increased arousal caused by caffeine ingestion will affect performance on this task. Lorist's model seems not to predict any differences in this task when caffeine is ingested, whereas a perspective derived from evolutionary psychology and the specificity hypothesis predicts that under increased arousal behaviour will shift towards a greater readiness for action. In the present task this may possibly be seen as a shift in the ratio of time given to holistic processing and focal processing in perceptual attention, that is a shift away from the processing of global stimuli towards local stimuli, since focal processing is required to scrutinize what is nearest (and possibly most threatening) to us.

It is still unclear how, in everyday settings, our visual system is able to construct a representation of detailed and widely distributed information, rapidly and apparently effortlessly, sufficient to prevent us from walking or driving into hazards presented by the environment. A plausible explanation of how such a feat might be managed is provided by Neisser's (1967) cyclic model of perception in which perception is initiated automatically and pre-attentively by sampling of sensory input, in a bottom-up fashion. If the resulting preliminary representation indicates a significant stimulus, attention is directed towards the stimulus and a perceptual hypothesis formed, aided by contextual information. This interaction of top-down and bottom-up processing creates an intermediate representation. If there is a match between the original preliminary and later intermediate representation, the intermediate representation is accepted. If there is a mismatch between the two representations, alternative intermediate representations are constructed until a match is found. Neisser's model has been found useful because it is able to accommodate the extraction of holistic, global properties and local features, together with the interaction of sensory, contextual and conceptual information.

In comparison, Navon's (1977) contention that perceptual processes are temporally organized, proceeding from global structuring to local analysis, and that global analysis

is fast and obligatory, whereas local analysis is slower and optional, resulting in the phenomenon of global dominance, seems a little static. From an adaptive perspective, such as that of the specificity hypothesis, it seems improbable that at any time local analysis should be optional. Particularly when under threat, it seems counterproductive to spend precious milliseconds surveying the whole visual field rather than attending to what is nearest, in the focal visual region, and therefore potentially more dangerous. If it should be found that increased neuroception of arousal caused by caffeine ingestion reverses the usual pattern of global dominance over local processing, this will provide concrete evidence that the effects of caffeine facilitate behaviours that promote survival.

In healthy people global dominance is almost always observed. It is not difficult to speculate on the adaptive value of such a mechanism in an evolutionary past where hazards such as predators were commonplace and best identified whilst still at a safe distance. In infancy, humans are at their most vulnerable, so it is perhaps not surprising that global dominance has been demonstrated in neonates (Cassia, Simion, Milani and Umiltà 2002) and four month old infants (Freeseaman, Colomb and Coldren 1993), in addition to remaining robust into old age (Bruyer, Scalquin and Samson 2003). Evidence from primate studies indicates that consistent patterns of hemispheric lateralisation for global/local processing have been found in baboons (Deruelle and Fagot 1997), macaque monkeys (Tanaka and Fujita 2000) tufted capuchin monkeys (Spinozzi, De Lillo and Truppa 2003) and rhesus monkeys (Hopkins and Washburn 2002), all of which exhibit a local bias, and in chimpanzees (Hopkins and Washburn 2002) which, like humans, demonstrate a global bias, suggesting a long evolutionary history of the global/local mechanism (Deruelle and Fagot 1997).

In addition, there is further evidence of the robustness of the distinction between global and local processing from observed double dissociation of function, for example, between individuals with obsessive-compulsive personalities (Yovel, Revelle and Mineka 2005) or Williams syndrome (Farren, Jarrold and Gathercole 2003), who are associated with a local processing style and individuals with Down's syndrome, who are associated with a global processing bias (Bihrlé, Bellugi, Delis and Marks 1989). Plaisted, Swettenham and Rees (1999) report that autistic children show local precedence in divided attention tasks but global precedence in selective attention tasks.

The present experiment offers the opportunity of making a comparison between the perceived salience of the global versus the local level stimuli, with and without caffeine ingestion. Since the global stimulus is almost universally identified faster than the local stimulus in normal, unstressed humans and the global task reported as 'easier' than the local, it is tempting to speculate that the particular cognitive architecture that evolved to promote this bias developed primarily as a source of 'ease of processing' or cognitive economy. However, though intuitively appealing, it is difficult to substantiate this argument. Why should a physically large H be faster and easier to identify than a physically small H, in structural terms, when there are an equal number of features to identify and presumably processes such as comparison and match to memory remain the same? Visual information processing is often described in terms of two levels, ambient and focal (Velichkovsky 1982). It has been demonstrated by Velichkovsky, Rothert, Kopf, Dornhöfer and Joos (2002) that increased arousal shifts visual attention from the ambient, or preattentive (parietal orienting system) level to the focal, or attentive (inferior temporal object-identification system) level. The mechanism for this shift in focus is a change in the sweep of large, but fast, saccades beyond the parafoveal region of the retina, where targets are not seen as individual items, to the longer fixations related to detailed focal processing. In situations of extreme stress, this shift in attention to the focal pole may result in 'tunnel vision', often reported by trauma survivors. Velichkovsky et al. show how, in a simulated driving study, hazardous, arousing events resulted in an increase in fixation duration at 'the cost of the proportion of preattentive fixations' (Velichkovsky, Rothert, Kopf, Dornhöfer and Joos 2002 p. 150), that is, increased arousal shifts visual attention processing towards detailed examination of proximal events, away from the scanning of more distant events beyond the foveal field.

In situations of potential threat, such a mechanism is likely to be adaptive. In relation to the present experiment, at baseline it is expected that a global superiority effect in RT will be evident, as is usual, but that post caffeine ingestion, due to increased arousal in participants in the caffeine condition, visual processing will be shifted to the focal level. This would result in relatively slower processing of the global stimuli, removing global superiority. More formally, it is hypothesised that there will be a significant interaction of RTs between caffeine condition and level of processing condition. As far as number of errors is concerned, since in the caffeine condition visual attention is shifted away from the global stimuli, it is hypothesised that there will be relatively more errors

occurring in the global condition and a significant interaction in number of errors between global and local processing and caffeine conditions.

5.3.2. Method

5.3.2.1. Design

A mixed (within-between), experimental design was used and inferential analysis carried out through analysis of covariance. In experiment 3, caffeine constitutes the between subject independent variable and global or local processing the within subject variable. RT 1, measured in milliseconds, and error 1 are the covariates whereas RT 2 and error 2 constitute the dependent variables. Participants were randomly allocated to either caffeinated or decaffeinated (control) conditions and the procedures carried out double-blind.

5.3.2.2. Participants

Participants were an *ad hoc* sample of 49 female social science undergraduates, aged between 18 and 52 years old, mean age 26 years. All participants reported being normal, moderate tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision.

5.3.2.3. Materials

A computerized version of Navon's hierarchical letter task, consisting of 36 global and 36 local trials, was used. Response time was recorded on the computer in milliseconds and number of errors indicated. Ingestion of mugs of caffeinated (80 mg of caffeine) and decaffeinated coffee provided the experimental and control conditions.

5.3.2.4. Procedure

Participants reported abstaining from any drink containing caffeine for the previous 12 hours and were allocated randomly to caffeine condition. At the beginning of the session, prior to drink administration (time 1: baseline), participants carried out the global/local task, following the instructions on screen. When this was completed, participants received, blindly, a mug of either caffeinated (80mg) or decaffeinated instant coffee, milk and sugar being added according to the participant's preference. All mugs were of the same size and design. After the drinks were administered, participants

filled out questionnaires (as a quiet, calm time-filler) for 20 minutes, and then repeated the global/local processing task (time 2).

5.3.3. Results

Data are described and displayed firstly in relation to RT and secondly in relation to number of errors.

5.3.3.1. Response Time

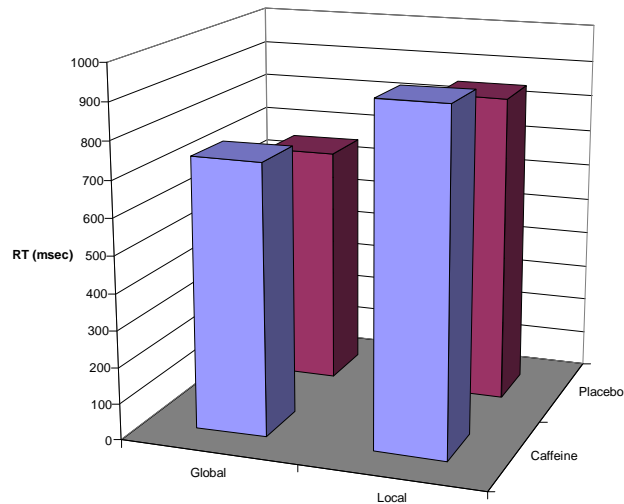
At time 1, before administration of the caffeinated or decaffeinated coffee, reaction times to the global stimuli were faster than reaction times to the local stimuli, illustrating the phenomenon of global dominance. However, at time 2, twenty minutes after drink administration, although global dominance is still evident in the decaffeinated condition, in the caffeine condition the position is reversed, local processing being faster than global processing. RT of global processing for the decaffeinated condition is faster by a mean of 275 milliseconds at time 2, whereas RT of global processing in the caffeine condition at time 2 is faster by a mean of only 151 ms, a little over half the ‘practice’ improvement seen in the decaffeinated condition. Conversely, improvement in RT to local processing at time 2 is very similar across the two conditions, being 345 ms for the decaffeinated condition and 356 ms for the caffeine condition, as shown in Table 5-3.

Table 5-3: Mean and Standard Deviation, Before and After Caffeine Ingestion, for RT (in milliseconds) to a Global and Local Processing Task

Caffeine Condition		Global		Local		N
		Mean	SD	Mean	SD	
Time 1	Decaffeinated	655	843	854	794	25
	Caffeine	741	515	924	570	24
	Total	697	696	888	687	49
Time 2	Decaffeinated	380	148	508	157	25
	Caffeine	590	301	568	256	24
	Total	483	257	537	211	49

It is plausible to assume that at time 2 a practice effect is in evidence, which would account for the faster overall RTs, but the improvement is different across both caffeine and processing conditions.

Figure 5-2: Differences Between Caffeine Conditions in Global and Local Processing RT Prior to Caffeine Ingestion

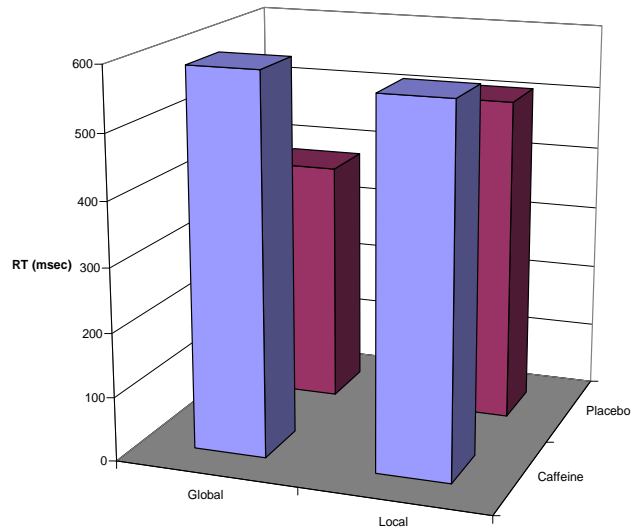


A mixed analysis of covariance shows that at time 1 there was no significant difference in RT between the two groups (see Figure 5-2), whereas at time 2, after caffeine or decaffeinated coffee had been consumed, there was a significant interaction between processing condition and caffeine condition on RT [$F(1,47) = 4.87, p < 0.05$]. In the global processing condition, the baseline RT covariate has no effect on global RT at time 2 but caffeine has a significant effect [$F(1,46) = 9.37, p < 0.01$] partial eta squared indicating that just under 10% of the variance in RT2 is due to caffeine, power $\beta = 0.94$. The interaction is shown in Figure 5-3, where it can be seen that in the placebo condition normal global dominance is still evident and response times fast, but in the caffeine condition global response times are significantly slower, demonstrating that the usual pattern of responses has been disrupted by caffeine ingestion.

These data indicate that the caffeine condition, unlike the decaffeinated condition, has differential effects on global and local processing. Caffeine has decreased, relatively, speed of processing in the global condition, though it has had no effect on the local condition. Analysis of covariance shows that for local processing, the covariate RT at time 1 has a significant effect [$F(1,46) = 7.351, p < 0.01$] on scores at time 2 but caffeine

has no effect. Consequently, the hypothesis that there would be a significant interaction between caffeine and processing conditions is accepted.

*Figure 5-3: Differences Between Caffeine Conditions in Global and Local Processing
RT After Caffeine Ingestion*



5.3.3.2. Accuracy

A similar pattern emerges when considering accuracy in global and local processing. At time 1 both groups made fewer errors in global than local trials, that is, a global error advantage was apparent (see Figure 5-4). However, by time 2, although global error advantage is still present in the decaffeinated group, it has disappeared in the caffeine group (see Figure 5-5).

*Table 5-4: Mean and Standard Deviation, Before and After Caffeine Ingestion, for
Number of Errors Made in a Global and Local Processing Task*

Caffeine Condition		Global		Local		N
		Mean	SD	Mean	SD	
Time 1	Decaffeinated	3.04	3.67	7.20	8.04	25
	Caffeine	3.67	7.25	5.04	6.00	24
	Total	3.35	5.66	6.14	7.12	49
Time 2	Decaffeinated	3.80	5.92	4.72	6.30	25
	Caffeine	4.46	5.45	3.41	5.80	24
	Total	4.12	5.64	4.08	6.03	49

Figure 5-4: Differences Between Caffeine Conditions in Number of Errors Made in Global and Local Processing Prior to Caffeine Ingestion

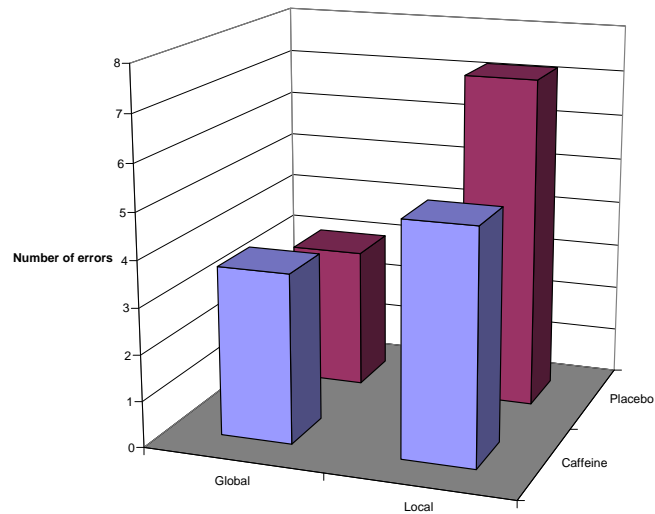
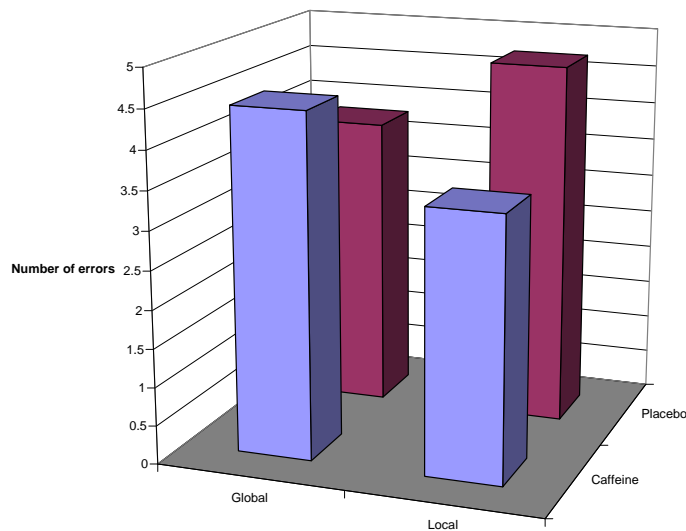


Figure 5-5: Differences Between Caffeine Conditions in Number of Errors Made in Global and Local Processing After Caffeine Ingestion



Mixed analysis of variance on difference between the number of global and local errors at time 1 is significant [$F(1,47) = 6.591, p < 0.05$] as would be expected, the global stimulus showing fewest errors. However, at time 2 there is no significant difference between number of errors in the global and local processing conditions, that is, the global error advantage widely found in the psychological literature has been disrupted by caffeine ingestion. These figures illustrate the changing pattern of errors between the

global and local processing conditions, caffeine removing the global error superiority effect.

5.3.4. Discussion

The data described above show beyond reasonable doubt that caffeine ingestion affects global and local processing differentially, though Lorist's model appears to contain no putative mechanism to account for these differences in performance. Within the framework of evolutionary psychology and the specificity hypothesis, it is argued that the increased neuroception of arousal shifts individual behaviour away from that appropriate to a safe environment towards that more appropriate for a less safe environment, resulting in a perceptual and attentional shift towards the focal pole. The argument that this shift is adaptive is substantiated by the different speed-accuracy trade-offs seen between the two processing conditions. In cognition it is normally the case that as RT is reduced, number of errors increases but in this experiment the speed-accuracy trade-off functions are very different between caffeine conditions. Local processing is relatively unaffected by caffeine ingestion whereas global processing is disrupted substantially, as far as both RT and error rate are concerned. Although an interpretation of this effect cannot be anything other than speculative, the perceptual and attentional switch from the 'forest' to the 'trees' is likely to be adaptive. Perhaps it would be more fruitful, rather than considering Navon's forest and trees analogy, to consider early humans faced with a pack of predatory animals or an army of hostile humans: though it is important to know where the bulk of the enemy is, from the perspective of survival, it is better to focus on those individuals close enough to inflict immediate damage.

There may be potentially important applications of caffeine's effects on global and local processing. Specifically, in situations where every millisecond counts, small differences in global and local processing times may be relevant to, for example, aerial surveillance, such as when police monitor traffic conditions, when armed forces monitor installations during peace keeping operations, when air traffic controllers are monitoring the movements of individual aircraft against a background of crowded skies and in attempts to understand and reduce road traffic accidents. In addition, this effect adds a further strand of explanation for the effectiveness of camouflage: when a target becomes part of a greater 'whole', the human visual system, under increased arousal, is likely to fail to

perceive a camouflaged target person or object. It is known that faces are processed globally, rather than by their features, which raises the possibility that individuals in a state of heightened readiness for action may be less able to recognize or recall faces. Since caffeine has been shown to disrupt global processing, it may be that a witness who has recently ingested caffeine will be less likely to make a correct identification: alternatively, if the witness were in a stressed state when he/she saw the suspect originally, state-dependent memory suggests that identification accuracy will be improved by the increased arousal caused by caffeine. This issue has potentially serious implications for eyewitness identification and merits further research.

5.3.4.1. Strengths and limitations of the study

A limitation of this study is that in this sample all participants are female. Although no gender differences in RT or accuracy are reported in the literature on global and local processing, caution needs to be exercised before generalizing the effects to males. A major strength of the study is that the design was mixed, so that it was legitimate to use analysis of covariance, thus partialling out the effects of individual differences on the dependent variables. A further strength is that the experiment was computer generated so that RT and errors were recorded very accurately.

5.4. General Discussion

Experiments 1 to 3, in which, firstly, one out of three card sorts was affected by caffeine ingestion and, secondly, RT and accuracy in global and local processing were affected differentially by caffeine, demonstrate that caffeine's effects on human information processing are more complex than can be accounted for by Lorist's model. In fact, Lorist's position is not always clear: in her model 'binary processes' are clearly located within 'central processing' and are said not to be affected by caffeine, as in 'caffeine has no effects on so-called higher mental processes performed in the central information processing stage' (1995 p. 131). However, a little later on the same page, she also states that 'effects found on indices of binary decision processes cannot unequivocally be interpreted as an effect on central processes', without any explanation as to when binary decision processing may, or may not, be considered due to central processing. Whilst acknowledging a considerable debt to Lorist's work, it is argued that the specificity hypothesis, which incorporates changes in behaviour under increased neuroception of threat and readiness for action (underpinned by changes in patterns of neural regulation,

as explicated by PVT and shifts in perceptual attention, from preattentive to attentive, as demonstrated by Velichkovsky), offers a more comprehensive framework for understanding and predicting the behavioural effects of caffeine.

Chapter Four has demonstrated high levels of caffeine use amongst young people and empirical data to suggest that level of caffeine use is implicated in behavioural traits such as impulsiveness and venturesomeness. The present chapter has provided further empirical data suggesting that categorization of novel stimuli and perceptual shift from ambient to focal attention are affected by caffeine ingestion: both of these changes in behaviour are seen as adaptive and directly related to readiness for action, fight-or-flight behaviours and the survival response and consequently offer potential support for the specificity hypothesis. However, it is argued that novelty in the environment must always represent a potential threat, until proven otherwise, so the ability to perceive novelty, through disambiguating figure and ground effectively, is of paramount importance to survival chances. Evaluating caffeine's effect, or lack of effect, on this process is seen as an important next step in assessing the usefulness of the specificity hypothesis and is considered in the next chapter.

Chapter Six

Caffeine and Seeing What is There

6.1. General Introduction

This chapter considers caffeine's effects on figure ground discrimination, together with self-reported stress and arousal and caffeine's effects on controlled processing in the Stroop task. It has been argued that caffeine ingestion moves an individual's state of readiness for action away from 'low readiness' as in coma or sleep, adaptive only in a situation of comparative safety, through increasingly higher levels of readiness for action in situations perceived as potentially less safe, in which fight-or-flight or escape and attack behaviours are manifested, through to situations perceived as life-threatening. In terms of evolutionary psychology, perception of threat and fight-or-flight behaviours are seen as manifestations of evolved psychological mechanisms, in the sense that they are sets of procedures which, historically, have usually been successful in solving recurrent problems of survival and reproduction.

Evolved psychological mechanisms are generally seen to possess the five properties. Firstly, the design features of any mechanism are specific to a particular ancestral problem or, as Tooby and Cosmides (1992) have argued, the psychological features are like a key made to fit only a particular lock. Secondly, evolved psychological mechanisms are designed to address a narrow sub-set of the information available, or a 'slice' of information, from the environment, which triggers an appropriate response. For example, it appears to be the 'slithery' way snakes move (as opposed to the 'long', 'thin' 'approaching' elements) that triggers an ancestral predisposition of fear of snakes found in humans and in many other animals (Buss 2004). Thirdly, the input from the environment on an evolved psychological mechanism indicates the kind of adaptive problem that is being faced, though the organism is not generally aware of this at a conscious level. For example, when hungry and faced with potential food sources, although mechanisms have evolved to guide the animal away from what it perceives as 'rotten' towards what it perceives as 'good' to eat, the organism is very unlikely to be consciously aware that it is facing and solving an adaptive problem of food selection. Fourthly, the information derived from environmental input is transformed through 'if, then' decision rules (Anderson 1996) into behaviour that has been adaptive in the past. For example, upon seeing a potentially poisonous spider, the options of attacking,

fleeing or freezing are available. Lastly, the output from an evolved psychological mechanism, which may involve physiological (e.g. autonomic arousal), cognitive (e.g. re-evaluation of the situation) and behavioural (e.g. running away) components, is directed towards the resolution of a specific adaptive problem, such as immediate survival. The initial interpretation of an environmental input is often dichotomous, as in 'friendly or ferocious' and 'nutritious or nasty', which underlines the importance of fast and accurate categorisation, once novelty in the environment has been registered.

Arguably the two questions most salient to survival in an environment of intermittent threat are 'is anyone/anything there?' and, if so, 'who/what is there?' Consequently, it is pertinent to the argument that caffeine use adaptive behaviours to consider the extent to which caffeine may enhance resolution of these questions. At present an understanding of the processes which underlie visual perception is far from complete, though a preliminary understanding, at the level of 'something' being there and how the 'something' is identified as a specific item located in space have attracted considerable research activity. Gregory (1998) argues that 'perceptions are hypotheses of what may be out there' and that 'perception is intelligent decision-making from limited sensory evidence...' (p. 5). In many senses, questions about the underlying mechanisms of sensation, perception and links between the two are beyond the scope of the present thesis and best left to experts in the fields of perception and visual information processing. However, an attempt at some basic level of understanding of how we see the world generally, and in particular how we become aware of change in the (visual) environment, is necessary in order to pursue the argument that changes in performance seen under caffeine ingestion are adaptive.

How precisely the brain is able to identify 'form' is still somewhat mysterious, although the function of various pathways in the primary visual cortex, or V1, have been identified. For example, Nealey and Maunsell (1994) distinguish between areas of high metabolic activity, or 'blobs', and areas of low metabolic activity, or 'interblobs', where the former respond to contrast and colour and the latter to contrast, location and orientation, in the P (parvocellular or small-bodied ganglion cells) pathway of the primate retina. In contrast the M (magnocellular or large-bodied ganglion cells) pathway responds to contrast and motion. These pathways have been described by Goldstein (1996) as the 'what' (P ganglion cell to inferotemporal cortex) and the 'where' (M

ganglion cell to parietal cortex) pathways. Although there is much for researchers to elucidate further it is clear that the brain invests considerable resources in attempting to answer the ‘what’ and ‘where’ questions and that this investment has been studied at biochemical, neuronal and cognitive levels. For example, at a cognitive level, the first question may be addressed on the basis of contrast sensitivity function and perceptual segregation, both seemingly good candidates for the initial perception of ‘something’, supported by the perception of edges, contrast, granularity (Julesz 1975) and the Gestaltist notions of the laws of proximity, similarity and good continuation. These notions are further underpinned by an analysis of separate streams of visual information processing, where the ventral stream of visual analysis identifies ‘what’ and the dorsal stream of visual analysis indicates ‘where’ (Styles 1997). From the perspective of evolutionary psychology, irrespective of the level of analysis being considered, the ensuing output addresses the resolution of a historically recurring problem of discerning what, if anything, is novel in the environment. In this thesis, inputs and outputs are considered at a behavioural level.

Survival is seen as paramount for any living creature and consequently monitoring the environment for potentially threatening change is a basic but essential function of cognition. The robust effects of caffeine on vigilance performance, or sustained attention, that is, the monitoring of subtle change in the environment, have been reported many times (see, for instance, Koelga’s 1993 review), which indicates that caffeine use offers an advantage in resolving the adaptive problem of maintaining safety. The fact that caffeine improves performance on a wide range of vigilance tasks may be seen as post hoc support for the specificity hypothesis. Caffeine’s effects on the more fundamental question of whether ‘anything’ is present in the visual environment, which appears to have attracted much less research effort, is the main focus of interest in this chapter and is addressed in terms of caffeine’s potential to improve speed and accuracy in the resolution of dichotomous alternatives. Firstly, caffeine’s effects on the resolution of the conflicting hypotheses of whether ‘something’ or ‘nothing’ is there, that is, perceptual segregation, are addressed directly, through the use of two embedded figures tests. An additional example of the resolution of competing hypotheses, in terms of task demands in the Stroop task, under different levels of arousal due to caffeine ingestion, is also considered.

Figure-ground discrimination, or perceptual segregation, and correct performance in the Stroop task necessitate the control of attentional processes and selection for action, which may be affected by the increased arousal caused by caffeine ingestion. In these tasks (as in many other tasks) in order to engage in coherent, goal-oriented behaviour a choice must be made as to which, of very many alternative stimuli found in typical environments, will be attended to and acted upon. Allport (1987) gives an example which is clearly relevant to survival chances:

‘A predator (a sparrow hawk, say) encounters a pack of similar prey animals, but she must direct her attack selectively towards just one of them; the fleeing prey must, with equal speed, select just one among the possible routes of escape’ (p. 396).

The number of courses of action open to us are severely limited at any one time by the number and range of our effector systems; for example, we can move our eyes, or hand, in only one direction at a time (Styles 2005). Hence, as Allport argues, there is a biological necessity for ‘selection for action,’ that is, a mechanism that selects, at motivational, cognitive, motor and sensory levels, which stimuli will be attended to and acted upon and which will be temporarily ignored. Since this process is likely to be crucial to survival under threat, the specificity hypothesis argues that such a mechanism will be susceptible to the effects of caffeine. As far as temporal organisation is concerned, perceptual segregation would seem to be a good candidate for early processing, so caffeine’s effect on field dependence-independence is considered first in this chapter.

6.2. Experiment 4: Caffeine Use and Field Dependence-Independence

6.2.1. Introduction

It has been argued that the most salient element of perception of the external environment is that of ‘something is there’, especially if the ‘something’ had not previously been present. From the perspective of the specificity hypothesis, it is to be expected that caffeine will enhance the ability to disambiguate shapes (prior to categorization) or, more formally, to separate figure from ground. If this proves to be the case it will provide further evidence for the usefulness of the present model of caffeine’s behavioural effects. The process of resolving what is seen into meaningful

images has been of considerable interest to psychologists for many years, ever since Witkin (1948) first recognised the significance of the ability to discriminate quickly and reliably between figure, or ‘signal’, and ground, or ‘noise’: or more colloquially, to separate the forest from the trees (Witkin, Lewis, Herzman, Machover, Meissner and Wapner 1954) and has been seen to have important implications. This ability has since come to be known as field dependence-independence (FDI). Given the historical context in which the phenomenon was first studied it was perhaps inevitable that FDI (like ‘intelligence’) was perceived as an aspect of personality revealed through perceptual style, rather than as a property of the visual cognitive system and research has largely focussed on reliable ways of measuring individual differences in separating figure from ground. Individuals who score higher on such tests are considered to be ‘field independent’ (and historically of superior intelligence) to those who score lower and are considered ‘field dependent’. Arthur and Day (1991) note that these ‘cognitive abilities relate to the level of performance and are more favoured at one end of the dimension (Fd/Fi) than the other’ (p. 851).

Although it is clear from the research literature that FDI is a robust and cross-cultural phenomenon (e.g. Adeyemi 1989 in Nigeria; Alansari 1997 in Kuwait; Brantley 2001 in Indonesia; Cakan 2003 in Turkey), research on the phenomenon has been dogged by contention and ambiguity, the most pressing issues being the nature of the construct *per se* and the extent to which FDI is best seen as a fixed personality trait or a malleable state. Witkins argues that differences in FDI reflect the concept of self-nonsel self segregation, a more differentiated person showing more self-nonsel self segregation and scoring higher on tests of FDI, and that such a difference ‘tends to show *absolute stability*’ over time (Witkin, Oltman, Raskin and Karp 1971 p. 6). If the heightened readiness for action induced by caffeine is able to shift scores on measures of FDI, if only temporarily, this may reduce some of the present ambiguity surrounding the concept, in addition to offering support for the specificity hypothesis.

There is some support for Witkin’s notion of FDI as a personality trait since, when the concept is examined in the area of business and organisational behaviour, FDs (field dependents) are found to excel at the more social aspects of business and to be team players (Hayes and Allison 1998; Leonard, Scholl and Kowalski 1999; Pithers 2002; Weiss and Shaw 1979). Significant differences in FDI have also been found in the area

of sports performance between acrobatic athletes and team athletes (tennis and table-tennis), the former being FI and the latter FD (Guillot and Collett 2004). The more active, analytical approach of FIs (field independents) described by Goodenough (1976) has some obvious advantages but in some circumstances leads FIs to becoming impatient with directions, preferring to work things out for themselves, which has resulted in their ignoring important instructions, missing deadlines and showing high levels of absenteeism (Summerville 1999). Wager and Willis (2005), in a simulated eyewitness identification scenario, found FIs less suggestible on a delayed, though not on an immediate, recall task.

6.2.1.1. FDI: a Measure of Self-discrepancy or Intelligence?

In some ways, aspects of Higgins' (1996) self-discrepancy theory offers a bridge between the notions of FDI as a measure of personality on the one hand and as a measure of readiness for action on the other. Higgins' theory incorporates a motivational self-regulatory system involving 'ideal' and 'ought' self-regulation, where the former is described as having a promotion focus, concerned with advancement, growth and accomplishment and the latter a prevention focus, concerned with security, safety and responsibility. Individuals considered FD are seen as socially and team orientated, which in Higgins' terms is likened to having a promotion focus, whereas FIs are seen as active, analytical and loners, likened to a prevention focus. Crowe and Higgins (1997) report that when faced with a set of difficult tasks, individuals manipulated into a promotion focus persevered longer, in the hope of gaining another correct answer, where individuals manipulated into a prevention focus gave up, rather than risk making mistakes. In terms of evolutionary theory, a safe environment may be seen to elicit a promotion focus, in which it may be advantageous to continue to pursue a desired goal, whereas a potentially less safe environment elicits a prevention focus, in which the cost of continued exposure to perceived threat may compromise survival. Since caffeine ingestion increases arousal and the neuroception of threat, it is hypothesised that caffeine ingestion will shift FDI scores towards the FI pole of the FDI continuum.

Alternatively, FDI has been seen as an aspect of intelligence (Vernon 1972), cognitive style (Messick 1976), cognitive control (Jonassen and Grabowski 1993) and spatial visualisation (McKenna 1990). Evidence for and against the above attempts to

encapsulate and define the concept of FDI has been inconclusive. For example, McKenna's notion of FDI as incorporating a visuo-spatial element is supported by the work of Miyake, Witzki and Emerson (2001), who report that spatial tapping, but not simple tapping, impaired performance on the Hidden Figures Test. On the other hand, the notion of FDI as cognitive style is challenged by other research evidence. Emmett, Clifford and Gwyer (2003), in a study of context reinstatement and eyewitness testimony, found an interaction between witnesses' FDI and their performance on context reinstatement and cued recall, where no such interaction was found between witnesses' performance and scores on the Cognitive Styles Analysis (CSA). Similarly, Le Blanc and Claverie (2000) failed to find a correlation between scores on the GEFT (Group Embedded Figures Test) and CSA when examining hypertext navigational styles. With respect to the stability of FDI, Goodman (1984), in a study in relation to the selection of naval aviators, reports a lack of intraindividual stability over time and Murphy and Doucette (1997) found that undergraduates studying business became both more analytically skilled and more FI throughout the period of their degrees.

From the perspective of the specificity hypothesis, measures of FDI may simply be measuring level of readiness for action. This does not necessarily conflict with McKenna's notion of spatial awareness, since it is feasible that increased readiness for action would incorporate a degree of increased spatial awareness. In general, one might expect to find individual, habitual differences in levels of readiness for action (analogous in this analysis to FDI), but in addition the specificity hypothesis predicts that environmental stress will shift individuals along the continuum of readiness for action, away from the FD pole towards the FI pole. If FDI measures not only a semi permanent predisposition but also captures a cognitive snapshot of a physiologically induced altered state, the lack of clarity in the empirical research record becomes understandable. The issue is not simple since both cognitive architecture and cognitive processes appear complex: it is generally accepted that there are two parallel streams of visual information analysis in the visual cortex, a ventral stream concerned with 'what' and a dorsal stream concerned with 'where' and the 'how' of action. In addition, there are different brain pathways concerned with transforming visual spatial information into a form appropriate for spatial movement (Styles 2005).

We do not presently have access to the many sub processes involved in the analyses and transformations of visual information processing and attempting to monitor streams of visual information is far beyond the remit of the present thesis. However, it is known that the distributed organisation of the visual cortex necessitates a mechanism that integrates and binds features of a perceived event and that caffeine ingestion, through stimulating the muscarinic cholinergic system, enhances the binding of shape and location and shape and colour (Lorenza, Colzato, Fagioli and Hommel 2005). It is argued here that the enhanced performance on the integration of shape/location and shape/colour is a further argument for caffeine's adaptive potential. Since caffeine enhances the binding of shape and location it would not be especially surprising to find that that caffeine also enhances the (presently unknown) sub-components of 'blobs' implicated in figure-ground discrimination, hence enhancing perceptual segregation.

6.2.1.2. Rationale for the Study

In seeking to evaluate the specificity hypothesis further, the present experiments utilizing measures of FDI may, in addition to clarifying caffeine's effects and further evaluating the notion of caffeine as eliciting adaptive behaviours, shed some light on the nature of the stubbornly ambiguous concept of FDI and its proposed stability. If the hypothesis that caffeine ingestion shifts scores on the FDI continuum towards the FI pole is upheld, the notions of FDI as a stable measure of personality and of habitual cognitive style are compromised.

The primary hypothesis being tested in the present thesis is that caffeine improves performance on behaviours that promote survival; arguably, since figure-ground discrimination tells us 'what is there' figure-ground separation, as measured by FDI, is such a behaviour and may show effects of caffeine ingestion. In addition, the notion that tests of FDI measure not only a semi-permanent, internal predisposition but also capture a cognitive snapshot of an environmentally induced, altered state of perception and readiness for action is evaluated. The behaviour that may promote survival is the enhancement of figure-ground discrimination, subsumed by the shift between ambient, preattentive visual attention (found pre caffeine) and the focal or attentive level of visual attention found under states of increased arousal and caffeine ingestion (Velichkovsky 1982).

In experiment 4, two versions of Witkin's embedded figures test are used: one using line drawings of real world objects, hidden within a larger line drawing of an extinct mammal, the Picture Embedded Figures Test (PEFT); the other using abstract 'simple forms' contained within 'complex forms', the Group Embedded Figures Test (GEFT). The rationale for choosing these two tasks is twofold: firstly, though both constitute embedded figures tasks, it is assumed that there are differences in the sub processes underlying the two tasks, since the latter involves identifying abstract, geon-like geometric shapes, whilst the former involves identifying everyday objects. Secondly, a pilot study showed that some participants had difficulty understanding what was required in the more abstract GEFT and it was found that having carried out the more easily understood PEFT earlier clarified the requirements of the second task. The primary intention behind this study is to evaluate the extent to which caffeine affects the perception of figure-ground, but a further point of interest is to consider whether caffeine shows similar effects on both types of test. The congruence of effects may shed some light on the extent to which these two embedded figures tests utilise the same cognitive processes. The hypothesis for this study is that caffeine will significantly affect performance on the GEFT and on the PEFT: underlying mechanisms activated by caffeine ingestion are presumed to be increased arousal and readiness for action, the shift from ambient to focal visual attention and a shift in regulatory focus from promotional to preventive.

Researchers routinely attribute changes in behaviour under caffeine ingestion to 'arousal' (e.g. Crowe and Higgins 1997; Hebener, Kagan and Cohen 1989; Kole, Snel and Lorist 1998), without defining the concept, whilst other researchers have found increased cortical and autonomic arousal after caffeine ingestion, as described in Chapter Two. However, one of the more persistent anomalies that arises in this area is that caffeine ingestion does not always show increased arousal. In addition, even when increased arousal is shown, caffeine ingestion does not always effect changes in behaviour and that one of these effects may be present without the other. Even when narrowing the difficult-to-encapsulate concept of 'arousal', to 'physiological arousal', as measured by heart rate, blood pressure, cholesterol levels, cortical arousal or galvanic skin response, or alternatively narrowing 'behaviour' to responses to visual choice tasks, no pleasingly regular patterns emerge: in a particular case one or more of these indicators may show an effect where others do not. Even within a specific field of

research, such as CVD research, indicators decline to coincide (Zuckerman 1991). The argument for preferring the phrase ‘readiness for action’, due to the problematic nature of the concept of ‘arousal’, was made earlier but in view of the historical link in the literature between the notion of arousal and caffeine ingestion, it is seen as appropriate to include a measure of stress and arousal in the present study.

6.2.1.3. Self Reported Stress and Arousal

An ideal measurement instrument, for the present purpose of evaluating the specificity hypothesis is one, which is able to measure both physiological arousal and psychological stress. The Stress Arousal Check List (SACL) is a self-report scale developed by Mackay, Cox, Burrows and Lazzarini (1978) and, according to the authors, is two-dimensional, measuring both these variables. According to the authors, in the SACL:

‘The first dimension is labelled as stress...[which] is considered a subjective experience in response to the external environment...This is a general sense of well-being...while the second [dimension] is labelled arousal...[which] represents ongoing somatic or autonomic activity’ (p. 340).

In other words, the first dimension is a response to the external environment, whilst the second is a response to the internal environment. It is argued through the specificity hypothesis that a combination of these two dimensions constitutes ‘readiness for action’ whereas, according to MacKay, Cox, Burrows and Lazzarini, higher scores on the separate scales of the SACL reflect more ‘stress’ and ‘arousal’ respectively. Those participants who receive caffeinated coffee, which has been documented to increase arousal on a number of objective and subjective indicators, are predicted to show greater increases in both stress and arousal, as measured by SACL, and to perform better on embedded figures tests. Robinson (1981) suggests, as a causal mechanism for differences on the FDI continuum, variation in the distribution of background cortical activity (known to be increased by caffeine ingestion), mediated by the diffuse thalamocortical system, which suggests that the ‘arousal’ subscale will show effects of caffeine whereas the ‘stress’ subscale may not. The SACL is not dissimilar to the amended Semantic Differential Mood Scale (Lorr and Wunderlich 1988) used by Crowe and Higgins in the regulatory focus/EFT study mentioned above.

6.2.2. Method

6.2.2.1. Design

This is a mixed (within-between), double-blind, experimental design, where caffeine constitutes the between subject factor, and ‘time’ (time 1 and time 2) the within subject independent variable. Correct identifications on the PEFT and GEFT, together with scores on the ‘stress’ and ‘arousal’ subscales of the SACL, at time 2 constitute the dependent variables. Participants were randomly allocated to either caffeinated or decaffeinated conditions.

6.2.2.2. Participants

An *ad hoc* sample of 35 Level 1 policing undergraduates acted as participants. There was a mix of males and females (20 female, 15 male) aged between 18 and 23 years old, mean age 19 years. All participants reported being non-smokers and normal moderate, tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision. Participants had been requested to abstain from ingesting caffeine for 12 hours prior to the experiment and confirmed that they had done so.

6.2.2.3. Materials

The psychometric instruments used are the Picture Embedded Figures Test (PEFT)(Witkin 1950), the Group Embedded Figures Test (GEFT)(Witkin, Oltman, Raskin and Karp 1971) and the SACL (Mackay, Cox, Burrows and Lazzerini 1978). The PEFT consists of a line drawing of a large mammoth, within which are hidden pictures of 12 items, such as a screwdriver, cap, pair of spectacles, etc (see appendix vi). These items are illustrated, in a panel above the main picture, as line drawings, and the task consists of identifying and encircling these hidden items within the main picture, each correct identification scoring one point. The GEFT consists of eight ‘simple forms’, which are contained within more complex geometric figures, in the same size, proportion and direction as the original ‘simple form’ (see appendix vii). The task is to identify and outline the simple form, each correct identification scoring one point.

The SACL contains 30 self-report items, where respondents are asked to describe their feelings and moods ‘at this moment’. Each of 30 adjectives is followed by a four point

scale indicating the degree to which the respondent feels, for instance, 'tense' or 'peaceful' (indicating psychological stress) or 'active' or 'idle' (indicating arousal). The SACL is a validated and widely used tool for measuring stress, as discussed above, for example, see McLoughlin, Armstrong, Byrne, Heaney, O'Brien and Murphy (2005).

6.2.2.4. Procedure

At the beginning of the test session, prior to drink administration (time 1: baseline) participants filled out the SACL and then carried out the standard form of the PEFT (2 minutes) and the GEFT (4 minutes), in accordance with the authors' instructions. After this was completed, participants received double blind a mug of either instant caffeinated or (placebo) decaffeinated coffee, milk and sugar being added according to the participant's preference. Participants then completed 'time filler' questionnaires about habitual caffeine use, during which time (30 minutes) it is assumed that the caffeine was absorbed through the bloodstream into the brains of the experimental group. The test procedures were then repeated, participants being asked to carry out the SACL, the PEFT (2 minutes) and the GEFT (4 minutes) for a second time. Examples of the PEFT, GEFT and SACL may be found in appendices vi, vii and viii.

6.2.3. Results

Means and standard deviations for correct identifications in both embedded figures tasks, before and after the administration of caffeine, are reported below. As can be seen, all scores improved at time 2, presumably due to a practice effect. The results of the analysis of covariance show correlations between performance on PEFT at time 1 and time 2 and on GEFT at time 1 and time 2 are, not surprisingly, significant but there is no correlation between the two different kinds of embedded figures tests, as shown by the Pearson's product Moment Correlation, GEFT 1 by PEFT 1 ($r = 0.30$, $p = 0.079$) and GEFT 2 by PEFT 2 ($r = 0.07$, $p = 0.67$), power $\beta = 0.38$.

In order to take account of individual differences in figure-ground discrimination at time 1, a multivariate analysis of covariance is considered appropriate and utilised. When this is carried out and alpha adjusted to $p = 0.013$, the effect of caffeine on the GEFT is found to be significant [$F(1,31) = 7.42$, $p = 0.013$] but the effect of caffeine on the PEFT does not reach statistical significance at $p = 0.037$. There are no statistically

significant effects of age or gender. Figures 6-1 and 6-2 give a graphical representation of the effects of caffeine on PEFT and GEFT at time 1 and time 2.

Table 6-1: Mean and Standard Deviation on the PEFT and GEFT, Pre and Post Caffeine Ingestion

Caffeinated/Decaffeinated		Mean	Standard Deviation	N
PEFT 1	Caffeinated	5.33	1.46	18
	Decaffeinated	4.88	1.32	17
	Total	5.11	1.39	35
PEFT 2	Caffeinated	9.61	2.25	18
	Decaffeinated	8.12	1.83	17
	Total	8.89	2.17	35
GEFT 1	Caffeinated	6.72	3.61	18
	Decaffeinated	6.12	2.76	17
	Total	6.43	3.19	35
GEFT 2	Caffeinated	11.22	5.64	18
	Decaffeinated	6.88	3.69	17
	Total	9.11	5.21	35

Caffeine's effects on psychological stress and arousal as measured by the SACL are shown in Table 6-2 below. Overall levels of stress have fallen but inspection shows that this fall is due entirely to the decaffeinated condition: stress in the caffeine condition has risen slightly. As far as physiological arousal is concerned, levels have risen between times 1 and 2 in both the caffeinated and decaffeinated conditions. The rise in arousal in the decaffeinated condition cannot be due to caffeine and it is difficult to speculate on the source of the change (unless it was excitement at the impending freedom from the constraints of the experimental situation).

Figure 6-1: Scores on the PEFT at Time 1 and Time 2 for Caffeine and Decaffeinated Groups

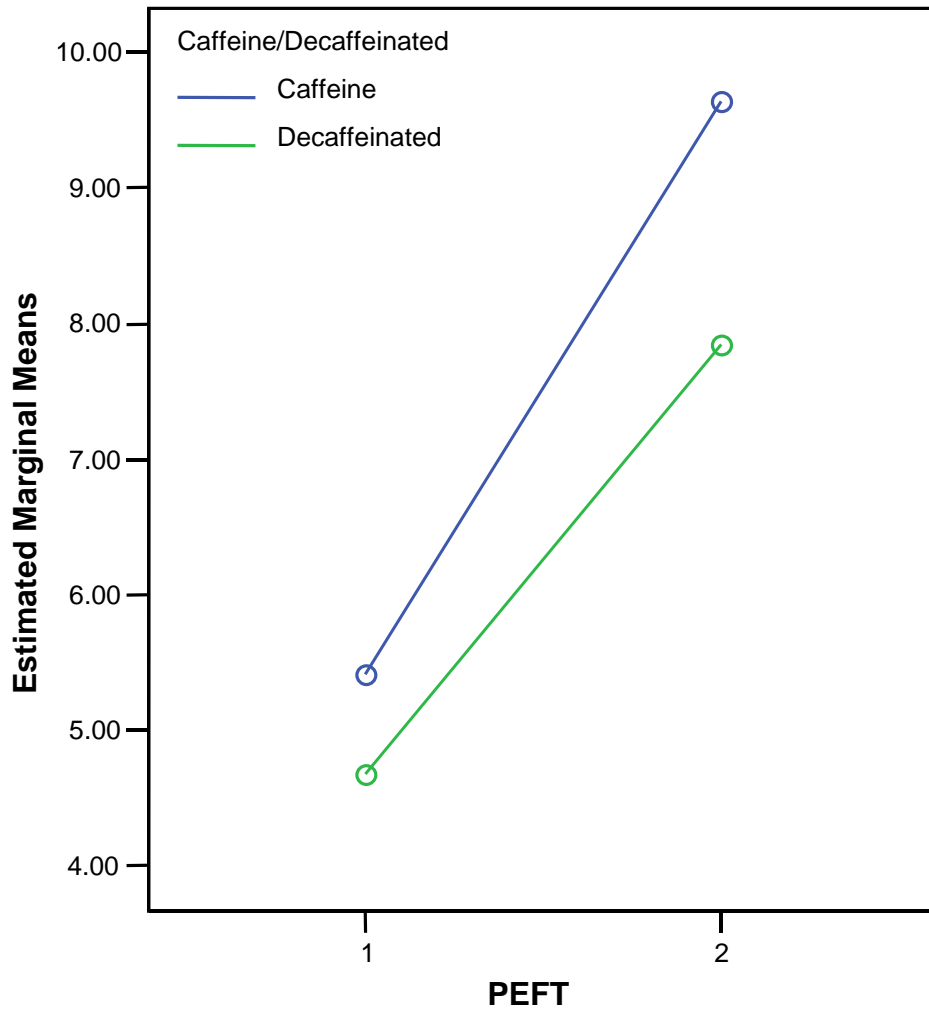
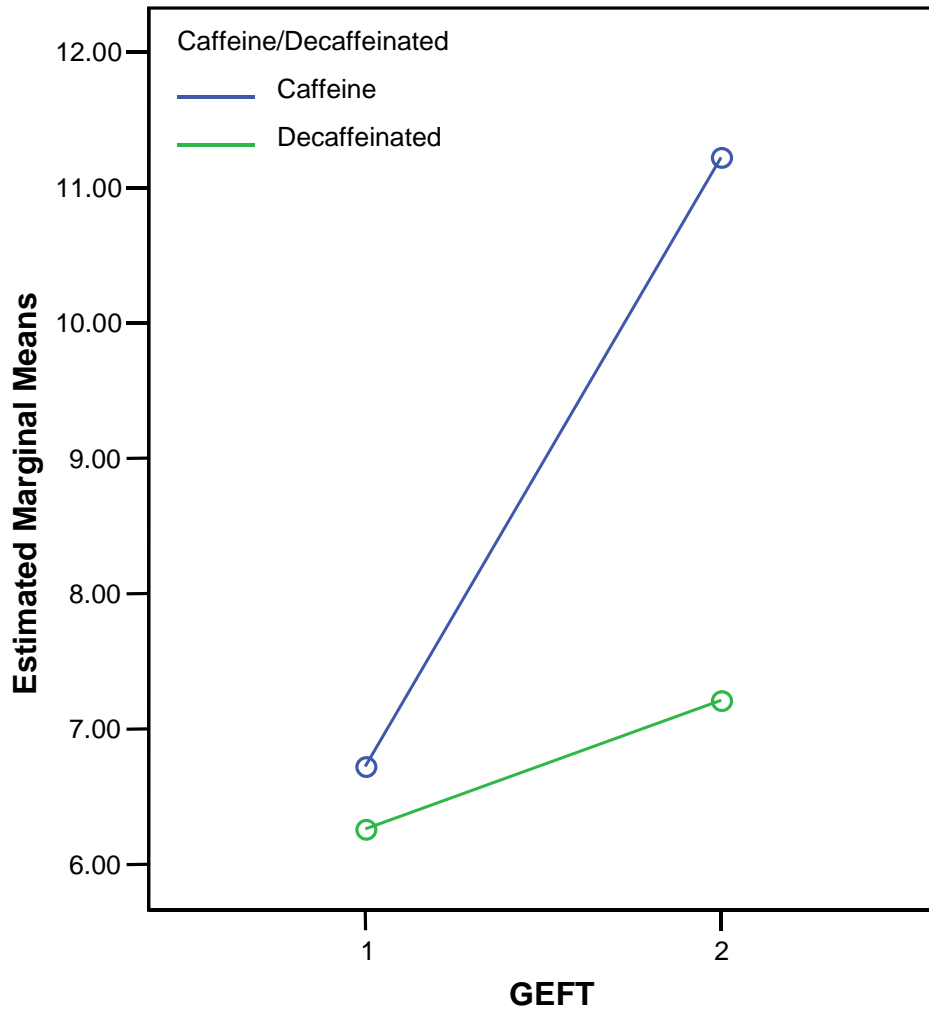


Figure 6-2: Scores on the GEFT at Time 1 and Time 2 for Caffeine and Decaffeinated Groups



6.2.4. Discussion

With respect to tests of figure-ground discrimination, it seems clear that the PEFT and GEFT are not measuring the same process, since no correlation was found between the two sets of scores. This is not perhaps especially surprising, since one might expect differences in the match to memory between the 'everyday objects' of the PEFT, presumably extracted from long term memory and the line drawings given, and the abstract geons of the GEFT. As regards the specificity hypothesis and the effects of caffeine on performance on figure-ground discrimination, the prediction that the increased arousal and readiness for action induced by caffeine ingestion would improve the ability to discriminate figure and ground is supported by the GEFT data. A

speculative interpretation of the trend towards a significant effect of caffeine on the PEFT might be that the, currently unknown, perceptual processes involved in figure-ground discrimination may have been affected by caffeine (as with the GEFT), whereas the memory elements of the PEFT task were not: memory is an aspect of cognition that has not been reported reliably as being affected by small doses of caffeine.

Table 6-2: Mean Levels of Arousal and Stress, Pre and Post Caffeine Ingestion

Caffeine/Decaffeinated	Mean	Standard Deviation	N	
Stress 1	Caffeine	3.83	4.11	18
	Decaffeinated	4.29	3.51	17
	Total	4.06	3.78	35
Stress 2	Caffeine	4.06	4.07	18
	Decaffeinated	3.63	3.10	17
	Total	3.86	3.58	35
Arousal 1	Caffeine	5.06	3.82	18
	Decaffeinated	3.65	3.70	17
	Total	4.37	3.78	35
Arousal 2	Caffeine	7.72	4.01	18
	Decaffeinated	6.23	3.90	17
	Total	7.00	3.97	35

As regards the wider concept of FDI *per se*, this demonstration of how easily scores may be manipulated by an everyday substance must cast doubt on the wisdom of the practice of using FDI in selection and educational settings. If the basic tenet of the specificity hypothesis is accepted, that is that increased neuroception of arousal leads to changes in behaviour through changes in patterns of neural regulation, not only caffeine but other environmental stressors are equally likely to affect FDI performance. Since the construct appears to be so malleable, the possibility of reconceptualizing FDI to include both ‘state’ and ‘trait’ dimensions (as with ‘state’ and ‘trait’ anxiety), on the basis of the data submitted here, has considerable appeal and also the potential to resolve some of the contradictions in the research record. Goodenough, when arguing that FDI is stable over time, was presumably referring to what is here termed ‘trait’ FDI.

When the nature of the concept of FDI is considered, without wishing to over-interpret the present data, it seems unlikely that a single dose of caffeine will change personality or intelligence. The notion of FDI as a measure of visuo-spatial perception has more appeal, particularly since it has been demonstrated in the previous chapter that a single dose of caffeine is able to disrupt normal patterns of global/local perception. The notion of FDI as a measure of spatial ability has particular appeal when seen through the perspective of Higgins' theory of regulatory control. The current thesis, that caffeine effects processes and behaviours that promote survival, argues that caffeine increases wariness and reduces impulsiveness, as reported in Chapter Four, whilst increasing readiness for action. The active, analytical behaviour and concern for safety, security and responsibility reported by Higgins as typical of a prevention focus sits very well with these findings and with the fact that caffeine has improved performance in a figure-ground discrimination task, that is, in 'seeing what is there'. These effects of caffeine on behaviour are seen as adaptive behaviours, offering further support for the specificity hypothesis.

6.2.4.1. Strengths and Limitations of the Study

A weakness of the study is that the mixed undergraduate sample were all engaged in policing studies and it is possible that policing students have particular characteristics that militate against extrapolation to the wider student community. Since this study was undertaken under laboratory conditions, it may be relatively low in ecological validity. Strengths of the study are that all materials used are well established for purpose and that analysis of covariance is able to take account of individual differences and practice effects.

6.3. Experiment 5: Caffeine's Effects on Cognitive Versus Emotional Processing in the Stroop Task

6.3.1. Introduction

The experiment on caffeine's effects on figure-ground discrimination reported above has demonstrated that increased arousal due to caffeine ingestion appears to direct attention to the 'foreground' rather than 'background' (as in local and global processing) and that this facilitates disembedding in the Group Embedded Figures Test, seemingly due to attentional switching, as described by Velichkovsky. This attentional switching is presumed not to be under voluntary control and it is therefore of interest to

see whether caffeine ingestion has a similar effect when attentional change is intentional. The Stroop task (Stroop 1935) is a complex information processing task in which selective attention must override perceptual intrusions if the task is to be completed correctly. In the prototypical or standard version of the Stroop test, a list of colour words is presented, each word being printed in a colour ink incongruent with the word's meaning, hence BLUE may be printed in red ink. The Stroop task is to name the colour of the ink whilst ignoring the habitual, default, response of reading the meaning of the word, that is, intentional change of attentional set is required.

It is self-evident that, when under threat, prolonged hesitation is likely to be counterproductive to survival. In the 1930s there was particular interest in interference to what would now be referred to as cognitive processes, Stroop remarking that 'Interference or inhibition (the terms seem to have been used almost indiscriminately) has been given a large place in experimental literature' (1935, p. 643). Despite the amount of work in the area few clear conclusions had emerged in relation to what was often referred to as 'habit interference'. In a (successful) attempt to move understanding of the issue forward, Stroop devised a new kind of experimental stimulus to test levels of interference: reading the name of a colour word printed in either black or conflicting colour ink and naming the colour ink, presented as either a block of colour or in a word spelling the name of a colour. In his original 1935 study, Stroop reported three experiments: the first consisted of timing participants when reading a hundred colour words (red, green, blue, brown and purple) either printed in black (list A) or a conflicting colour (list B); in the second experiment participants were asked to name blocks of colour (list C) and then asked to name the colour of the ink of each word in list B (the 'Stroop', or incongruent, condition); the third experiment examined the effects of eight days of practice on the different tasks. Stroop found a small, non-significant level of interference caused by coloured ink in experiment 1 (an increase of 5.6% over the time needed for reading black ink) but a large difference (an increase of 74%) between naming the colour block (list C) and naming the ink colour of conflicting colour names (list B). This kind of interference has become known as the 'Stroop' effect. Practice 'was found either to increase or to decrease the variability of the group depending upon the nature of the material used' (p. 661).

The Stroop test has been of interest to psychologists ever since its development in 1935 (for example, see MacLeod 1991). Performance on the test has been linked with automatic processing (since although instructed to name the ink colour most people find it difficult to ignore the meaning of the word) and there has been considerable discourse on the cognitive and emotional sub-processes underlying the Stroop effect. Typically, participants are significantly slower at naming the ink colours than reading the list of words, presumably because the resolution of conflict between the largely automatic processes of reading and colour naming requires time; in fact many participants make occasional errors and read the meaning of the word instead of naming the ink colour. The notions of cognitive interference and competing hypotheses are entirely plausible, though performance on the Emotional Stroop (Gotlib and McCann 1984) argues that, though necessary, these explanations may not be sufficient. Although apparently eliciting a degree of cognitive confusion, the basic Stroop task does not appear to be especially threatening. When, however, emotionally salient words are introduced, as in the Emotional Stroop, or when participants are experiencing heightened levels of anxiety during the Stroop task, such as when snake-fearful participants are exposed to a snake (Mathews and Sebastian 1993) or patients with social phobia are due to give a speech (Amir, McNally, Riemann, Burns, Lorenz and Mullen 1996), the Stroop effect disappears, that is, there is no longer a time difference between performance on reading the word list (control) and naming ink colour (Stroop) tasks. It seems that perceived threat, presumably through the mechanisms of changed neural regulation due to increased arousal, resolves the conflict of competing stimuli faster than when no potential threat is present. From the perspective of evolutionary psychology and the specificity hypothesis, this faster resolution leaves the individual ready to take action appropriate to surviving threat earlier and hence has the potential to enhance survival.

Botvinick, Braver, Barch, Carter and Cohen (2001) have put forward a model of conflict-monitoring, presumed to represent the activity of the Anterior Cingulate Cortex (ACC). The system enhances top-down cognitive control when it detects competing demands (under normal, stress-free conditions). Bush, Luu and Posner (2000) and Drevets and Raichle (1998) have demonstrated that the ACC consists of two subdivisions, containing cognitive and emotional components respectively, which fMRI studies have shown to be mutually inhibitory, so that a cognitive task reduces activity in the emotional subdivision of the ACC and vice versa (Wyble, Sharma and Bowman

2005). This offers a potential explanation for why performance on the incongruent Stroop task is seen to improve with practice, since repeated exposure to emotional stimuli is known to reduce stress (desensitization), in this case, presumably to the point where the cognitive subdivision of the ACC is able to become dominant. In addition, the model offers a rationale, in both theoretical and functional terms, for why the Stroop effect seems to 'disappear' when participants' arousal is increased, from either exogenous environmental stress, such as fear inducing stimuli, or endogenous arousal, as result of, for example, ingesting a substance with excitatory effects, such as caffeine. Cognitive control, or top-down processing, is in conflict with the emotional demands generated by the perception of stress and it would seem that in such a situation the emotional component wins. McKenna and Sharma (2004) offer an elegant example of different responses to cognitive and emotional stimuli in a version of the emotional Stroop paradigm, which offers an illustration of how the emotional component of the ACC appears to override the cognitive component. In their version of the Stroop test, neutral or negatively valenced emotional words, such as, 'fear', 'fail' and 'grief' are used instead of the typical colour words. Participants were presented with a list of seven neutral words, such as 'gate', 'clock' and 'note' and asked to name the ink colour, as in the standard Stroop task, but every second word in each seven word list was negatively valenced, that is, there were six neutral and one negatively valenced word in each list. McKenna and Sharma found that although the negatively valenced word was responded to as quickly as the neutral words (mean 920 milliseconds), the following neutral word was responded to significantly more slowly (a 6.5% increase). This is in direct contrast to the slowing of responses in the standard Stroop task, where it is the incongruent trial itself on which the delay is found. McKenna and Sharma describe their finding in terms of a 'slowing effect', which is interpreted in terms of the emotional words causing elevated activity in the emotional subdivision of the ACC and suppressing activity in the cognitive subdivision, hence reducing cognitive control and delaying the resolution of the competing hypotheses.

There are a variety of experimental paradigms (most obviously in relation to the study of infants in developmental psychology, for example, the 'scrambled faces' of Fantz, 1961) where 'longer looking' is interpreted as a sign of interest. It is conceded that looking longer at a stimulus may, again, be due to the need to resolve competing hypotheses (clearly not consciously articulated in the case of neonates), along the lines

of ‘do these shapes, in this pattern, represent the same thing as when the same shapes are in a specific (face) pattern?’ There are other circumstances where looking longer may be accounted for by the notion of resolution of competing hypotheses. For example, in the orienting reflex, where increased arousal (e.g. from caffeine ingestion or perceived threat) extends the duration of the reflex which may, alternatively, be interpreted as having a threat-evaluative function. It is conceded that there may be some overlap between these different interpretations; for example, it is possible that during the (e.g. caffeine-induced) extended orienting response, at an unconscious level, there may be conflict between notions of ‘I feel increased threat’ but ‘I see nothing to indicate increased threat’. According to Wyble, Sharma and Bowman (2005), the increased neuroception of threat would inhibit cognitive control and in terms of the McKenna and Sharma (2004) model this would be sufficient to produce a ‘slowing effect’. This stalemate is, presumably, resolved only by an evaluation of the level of perceived threat in the environment: in the natural world an animal will ‘decide’ that the level of threat is inconsequential and take no action or that it is potentially dangerous and act accordingly.

Cognitive bias in relation to the Stroop test has been reported by a number of other authors. For example, Martin, Horder and Jones (1992) report cognitive bias towards spider-related words in a sample of 6-7 year old spider-phobics and Power and Dalgleish (1997) report a similar cognitive bias related to anxiety. This pattern of behaviour is predictable from the perspectives of evolutionary psychology and the specificity hypothesis since increased anxiety is likely to cause a changed pattern of neuoregulation, interpreted by the body as increased perceived threat and hence the suppression of cognitive control, as suggested by McKenna and Sharma. It is of interest to note that such biases are associated with ancestral fears (e.g. of spiders) rather than with genuinely dangerous elements of the modern world (e.g. electrical sockets). Richards, Richards and McGeeney (2000) report a differing pattern of results in a sample of ‘high anxiety’ adolescents who ‘looked longer’ at anxiety-related words (crazy, tense, panic, fear, shaking, nervous, dying, frightened) where their ‘low anxiety’ peers did not. It may be feasible to argue that participants in the ‘low anxiety’ group were not sufficiently aroused by the anxiety related words for cognitive suppression to be challenged, whereas their more anxious peers, starting further along the anxiety

continuum, more readily reached the point at which the emotional component of the ACC overrode the cognitive component.

Neshat-Doost, Taghavi, Moradi, Yule and Dalgleish (1997) found no Stroop effect in a sample of depressed participants, when using a version of the Stroop test modified towards depressive symptoms. Richards, Richards and McGeeney suggest, as an explanation for these conflicting findings, that interference (in the Stroop test) may be more strongly related to anxiety than to depression, though they do not offer any theory or rationale as to why this should be so. From the perspective of the specificity hypothesis and Polyvagal Theory, there is a straightforward explanation: depressing words would likely exacerbate further the flattened affect and low levels of emotional arousal associated with depression: hence, as suggested by Bush, Luu and Posner (2000), cognitive control would override emotional aspects of the task and hypothesis resolution would be speeded.

An alternative explanation is that the depression-related words were too generalised to elicit upregulation of the neuroception of threat, whereas a specific depression-related threat word, such as 'suicide' may have produced differential responses. Since it may be seen as unethical to expose depressives to such a negatively valenced concept, the notion of specific threat is examined in relation to anxiety. It is argued that words relating to a specific perceived threat, for example, phobia-related words, will increase arousal, which will affect performance in the Stroop task. Since caffeine has been shown to speed perceptual processing, it is hypothesised that in the standard Stroop task, the caffeine condition will resolve the conflict between naming the ink colour and reading the word significantly more quickly than the decaffeinated condition. On the other hand, it is hypothesised that phobia-related words will remove or reduce this advantage since the emotional component of the ACC (presumed to monitor threat) may override the cognitive component (presumed to activate conflict resolution) and a slowing of processing will become apparent. In other words, it is also of interest to examine whether in a 'phobic' form of the Stroop test response time will be further reduced, by two concurrent stressors, or whether the two stressors together will exceed the optimal level of arousal for best performance.

In an attempt to pursue these ideas further, a new form of the Stroop test was devised and piloted. Since the specificity hypothesis argues that perceived threat affects behaviour, through the mechanisms of a changed pattern of neuroregulation, the new form of Stroop is designed to tap into threat-induced arousal, utilising phobia-related words.

6.3.1.1. Development of Phobia-Related Stroop Test

Initially, after a discussion of what constitutes a rational fear as opposed to a phobia, 38 undergraduates were asked to make a list of ten items which made them fearful and then to list these items in order from most to least threatening. This information was collated and coded numerically ('most threatening' coded as 10, 'least threatening' as 1) and individual items assigned an overall 'threat level'. From this list the twelve words with the highest 'threat level' (snake, spider, rat, mouse, insect, birds, worm, blood, crowd, germ, needle, knife) were extracted, to be used as stimuli for the phobia-related Stroop. In an attempt to assess the extent to which this new list does in fact measure phobias, as opposed to more general fear, the items were compared with the twelve items which received highest intensity ratings in the Fear Survey Schedule (Greer 1965). Only one word, 'snake' appears in both lists, the other items in the Fear Schedule being quite different in nature (suffocating, failing a test, looking foolish, making mistakes, illness or injury to a loved one, not being a success, speaking before a group, death of a loved one, untimely or early death) to those elicited in the 'phobia' workshops. In order to find control words which match the phobia-related words in length and frequency of use the Frequency Analysis of English Vocabulary and Grammar (Johansson and Hofland 1989) was consulted. All words selected for the 'neutral' version of the 'phobia-related' Stroop were concrete nouns and hence easy to associate with visual images (couch, guitar, cakes, wall, earth, bread, duck, muscle, chain, bunch, nation, gym) in order to be similar in profile to the phobic words elicited from respondents initially. Both new versions of the Stroop test were piloted on undergraduates and subjected to Cronbach's alpha. The correlation coefficients being 0.89 (standard Stroop) and 0.83 (phobia-related Stroop) respectively ($n = 38$), the new versions of the Stroop test (see appendix ix) were considered adequate and utilised in the following experiment.

In order to confirm face validity, and that the 'phobic' list and the 'neutral' list measure different underlying constructs, 50 undergraduates were timed, by stopwatch, on

naming the colour of the ink in which both sets of words are printed, the order of lists being counterbalanced. The mean time for the 'phobic' list was found to be 16.84 seconds, with a standard deviation of 2.97 seconds, whilst the mean time for the 'neutral' list was found to be 17.60 seconds, with a standard deviation of 3.64. A related t-test indicates a statistically significant difference in time between the two lists, ($t = 2.285$, $df 49$, $p < 0.027$). The 'phobic' Stroop appears, therefore, to be a useful and valid addition to measures of cognitive/emotional interference in processing. From the perspective of evolutionary psychology (and common sense), it is not surprising that participants responded more quickly to fear-related words than to neutral words, since faster response to something frightening in the environment would likely aid escape and so be adaptive.

It has been argued that a fast response to fear-inducing stimuli has the potential to be adaptive and also that caffeine enhances behaviours that have the potential to be adaptive. In order to pursue further the thesis that caffeine use is adaptive, caffeine's effect on the new standard and phobic versions of the Stroop test is now examined.

6.3.2. Method

6.3.2.1. Design

This is a mixed (within-between) double-blind, experimental design, caffeine condition being the between subject independent variable and Stroop condition ('neutral'/'phobic') being the within subject independent variable. Time (to the nearest tenth of a second) on the Stroop tasks provides the dependent variables.

6.3.2.2. Participants

An *ad hoc* sample of 50 first year undergraduates, reading for Criminology, Sociology, Psychology or Policing Studies degrees served as participants, age 18-52, mean age 25.7 years, 42% male.

6.3.2.3. Materials

High caffeine cola (RAC 124), containing 124 mg of caffeine, and decaffeinated cola, card versions of both the standard and phobic (as described above) Stroop tasks, plus stopwatches.

6.3.2.4. Procedure

Participants confirmed that they had refrained from drinking caffeine-containing drinks for the previous 12 hours and then were randomly allocated to caffeine condition and offered a (disguised) can of either high caffeine or decaffeinated cola to drink. Fifteen minutes later they were timed, by stopwatch, whilst carrying out both versions of the Stroop test, in counterbalanced order.

6.3.3. Results

In the 'neutral' Stroop condition, the decaffeinated group are slower and show a wider standard deviation in their responses, though in the 'phobic' Stroop condition these differences are less substantial. This pattern of responses is summarized in Table 6-3.

Table 6-3: The Effects of 'High Caffeine' and 'No Caffeine' on Responses to 'Neutral' and 'Phobic' Versions of the Stroop Test

Time to Complete Task (seconds)		Mean	Standard Deviation	N
Neutral Stroop	High Caffeine	15.80	2.40	26
	Decaffeinated	17.50	3.50	24
	Total	16.62	3.07	50
Phobic Stroop	High Caffeine	16.38	2.33	26
	Decaffeinated	16.83	2.88	24
	Total	16.60	2.60	50

When the data are subjected to mixed analysis of variance, a main effect of caffeine is not found, $p > 0.05$, though eta squared suggests 4.3% of the variance in performance is due to caffeine's effects. Similarly there is no overall difference in time between the two Stroop conditions. However, a significant interaction of caffeine condition with Stroop condition is found, [$F(1,48) = 4.179$ $p < 0.046$]. These data may be interpreted to mean that, in the standard Stroop condition, caffeine has speeded the response, compared to the decaffeinated condition, by 1.7 seconds, but that the phobic Stroop condition has elicited differential effects on the high caffeine and no caffeine conditions. The fear-inducing stimuli appear to have speeded the response (unusually) in the decaffeinated condition, but slowed it in the high caffeine condition, hence there being no main effect of caffeine seen. In other circumstances, these very small differences may be of interest but, given that the timing was recorded by manual

stopwatch, the safest interpretation appears to be that there is no effect of caffeine on the phobic Stroop test.

6.3.4. Discussion

The differences in patterns of performance found in the two versions of the Stroop test confirm that the 'phobic' Stroop is a useful addition to measures of the Stroop effect. Any discussion of the presumed underlying mechanisms of this difference must inevitably be speculative, particularly since timing by stopwatch cannot be considered especially accurate and may be prone to human error. However, the data suggest that caffeine aided the resolution of the conflict inherent in the standard Stroop task. It may be that under the increased arousal caused by caffeine ingestion, perceptual attention is more readily focussed on the simple task of colour processing rather than on the cognitively more demanding (if over-learned) task of reading, in the neutral Stroop condition. Alternatively, it may be that under caffeine's effects the 'decoupling' of stimulus elements irrelevant to the task at hand becomes easier. This explanation is in line with the findings from the enhanced perceptual segregation demonstrated through the GEFT task above. In addition, the requirements of the task can then be seen as not dissimilar to those required for sustained attention tasks, where caffeine's positive effects are well documented.

When considering the data for the 'phobic' Stroop, it appears that the threatening nature of the words presented caused sufficient increase in arousal in participants in the decaffeinated condition to reduce mean response time by 0.67 seconds. However, in the high caffeine group, the mean has increased by 0.58 seconds, when faced with threatening words. This differential change in response to the different Stroop conditions is open to a number of possible interpretations. The hypothesis that caffeine would speed perceptual response and conflict resolution in the standard Stroop task is supported, as is the hypothesis that the increased arousal generated by phobia-related words would slow responses, presumably due to the cognitive component of the ACC being overridden by the degree of threat being perceived.

Though not possible within the constraints of the present research, one way of pursuing these hypotheses further would be to introduce not only the phobia-related word 'spider' to the two caffeine conditions, but an actual spider, such as a pet tarantula. It is

suspected that some, though not all, participants would find this a more stressful experience than merely reading aloud phobia-related words, that is, a live tarantula would represent a significantly higher level of perceived threat than either ingesting a moderate amount of caffeine or reading the word 'spider' and consequently have measurably different effects on behaviour. Perhaps, as Broadbent (1971) has suggested, reliance on the term 'arousal' (despite its confused conceptual status) is clouding the issue here. If 'readiness for action' rather than 'arousal' is substituted, the experimental data are perhaps easier to understand. Caffeine ingestion has primed the caffeine group for action, speeding perceptual response, but when they are subsequently faced with a potential, if hypothetical additional stressor, an additional evolved psychological mechanism related to evaluation is activated. The presence of a real threat (e.g. a pet tarantula) rather than a hypothetical additional stressor may be sufficient to raise the level of alarm, physiologically speaking, further, which has the potential to test the notion of an additional evaluative function. Though this promises to be an interesting avenue to follow up, it is beyond the scope of the present work.

6.3.4.1. Strengths and weaknesses of the study

The study was carried out double-blind, reducing the risk of experimenter expectancy and social desirability effects. A weakness is the potential for human error when a stop watch is used, although it was noted from earlier pilot studies that participants seemed to 'see' the target shape either more or less immediately or not at all, so accuracy of timing may not be as critical in this task as in many others. The use of an *ad hoc* undergraduate sample restricts the generalisability of the findings, though the institution from which the sample was drawn has enthusiastically embraced the concept of widening participation, so the sample was not the white, middle class undergraduate stereotype of yesteryear.

6.4. General Discussion

In this chapter, examples of the resolution of conflicting hypotheses, with and without caffeine, have been considered. Since hesitation might well offer a potential predator an advantage, it is to be expected that psychological mechanisms to resolve conflicting hypotheses quickly would evolve: since the thesis being pursued here is that moderate caffeine use is adaptive, it was hypothesised that caffeine use would further speed this resolution.

In the perceptual segregation, Group Embedded Figures Task, the hypothesis to be resolved relates to the ‘is anything/nothing there?’ question, the speedy resolution of which is likely to confer survival advantage, and caffeine was shown to improve performance significantly. The Picture Embedded Figures Test was found neither to correlate with the GEFT, nor was performance on this task affected significantly by caffeine use. This raises both the question of the extent to which the PEFT is a valid measure of FDI and the extent to which improved performance might be seen as adaptive. In contrast to the GEFT, it is less easy to see how performance on the PEFT (where a seen picture has to be found ‘hidden’ within a larger picture) has immediate adaptive relevance. If the target pictures were not presented but had to be generated from memory, so that the task became, for instance, ‘find a crescent moon shape within the large picture’, the process would become more relevant to noticing salient features within a landscape (such as food items or concealed predators), which may arguably be seen as being more ecologically valid and having more adaptive potential than the PEFT used here.

However, in the present state of knowledge, it is difficult to speculate on whether the different cognitive demands of the GEFT and PEFT (the latter requiring the use of memory for familiar items where the former is purely a perceptual segregation task) account for the different patterns of results under caffeine ingestion or whether, as may be argued from the perspective of the specificity hypothesis, the difference is due to enhanced performance on the GEFT having a greater potential to improve survival chances than improved performance on the PEFT offers.

With respect to the lack of clear effects of caffeine on ‘stress’ and ‘arousal’, which is contrary to the consensus in the literature, it seems likely that the subjective nature of the measurement instrument (self report check list), as opposed to more objective physiological measures used in much prior research, may provide at least a partial explanation, although as discussed above, physiological measures of stress do not correlate with one another or with subjective measures of stress. It may be that the SACL is not sufficiently sensitive to show any caffeine-related effects and that the utilisation of a more objective indicator of increased arousal, such as salivary cortisol, would be beneficial.

With regard to the Stroop test, there is an additional methodological problem that needs to be considered in future work in this area. As Richards, Richards and McGeeney (2000) have pointed out, there are cognitive biases present that relate to anxiety which, if not taken into account, may obscure true effects. These researchers found that, when participants were assigned to groups on the basis of their scores on the Beck Anxiety Inventory (Beck, Epstein, Brown and Steer 1988), the high anxiety group took significantly longer to identify colour in the threat-related words than in the neutral words, whereas there was no difference found in the low anxiety group. This suggests that researchers carrying out future work using the Stroop paradigm would be well advised to consider levels of trait anxiety before inducing Stroop-related state anxiety in participants.

Chapter Seven

Caffeine's Effects on Elements of Visuo-Spatial Ability

7.1. General Introduction

Previous chapters, in which experiments show the effects of caffeine on behaviour, offer tentative support for the notion that caffeine promotes adaptive behaviours; caffeine has been shown to reduce venturesomeness, to improve performance on a categorisation task, to switch attentional resources away from global towards local stimuli, to improve figure-ground discrimination and to affect the allocation of visual attention. In situations of uncertainty or perceived threat, all these changes in behaviour may be adaptive, firstly through enabling the earlier identification of potential threat and secondly through extended physical and mental endurance (in the sense of sustained attention and motivation) which results in part from the prolonged release of calcium into the bloodstream. However, the findings of these experiments raise as many questions as they answer, particularly in relation to the awareness of change in the environment, change always having the potential for threat, until proven otherwise.

If the decision as to whether 'something' or 'nothing' is there is the question most salient to survival, arguably, answering effectively the question of *what* is there is the next most important. Before being able to categorise a stimulus as something specific, in order to answer the 'what' question, the perceiver must first identify the stimulus, that is object recognition has to occur. A detailed discussion of the complexities of object recognition is beyond the remit of the present thesis, though a decision as to where one object ends and another starts, size and shape constancy and an ability to recognise an object from many angles are clearly important elements of the process and prerequisites to recognition and categorisation.

The issue of ease of categorisation is seen as significant in relation to the evaluation of the specificity hypothesis, since 'Rapid categorisation obviously facilitates our survival and interaction with the environment on an everyday level' (Grill-Spector and Kanwisher 2005 p. 152). In a series of experiments in which *object detection* (or perceptual segregation/figure-ground discrimination), *categorisation* (i.e., between groups, such as 'car' or 'bird') and *identification* (i.e. within category, such as 'pigeon' or 'parrot') were investigated pictorially, Grill-Spector and Kanwisher found that

participants are as fast and accurate in categorisation as when deciding whether or not an object is present, that is, as soon as ‘something’ is discerned participants know its general category. The authors conclude that ‘There are two main processing stages in object recognition, categorisation and identification, with identification following categorisation’ (p. 152). Hence it is assumed that the ability to create mentally a ‘whole’ image (sufficient for categorisation) from a partial view is normative, so good visuo-spatial ability is likely to be adaptive. This chapter examines caffeine’s potential to enhance performance in four different tests of visuo-spatial ability, all of which involve some degree of mental image rotation, which is seen as a key element of object recognition.

7.1.1. Theories of Visuo-Spatial Ability

Though the notion of visuo-spatial ability is clearly important in attempting to understand perception and cognition, the precise nature of the concept is problematic. There is general agreement about the existence of a visuo-spatial sketchpad in working memory, as proposed by Baddeley and Hitch (1974), but less agreement about how visual and spatial information is represented in long term memory. Kosslyn (1980) argues for an analogue representational system where images are represented in a spatial medium, within which images may be scanned and manipulated. Pylyshyn (1981), on the other hand, argues that mental images are represented propositionally and relationally and that the subjective experience of ‘pictures in the head’ derives from the tendency of individuals, when engaging in mental imagery, to behave in the way that they know they would if they were dealing with real images. Pavio (1986), in proposing a dual code theory, in which images are coded both verbally (logogens) and visually (imagens) and where one or both systems may be activated depending on the context and specific attributes of a stimulus, offers a perspective which incorporates the essence of both Kosslyn’s and Pylyshyn’s theories. Implicit in all these theories, regardless of how exactly the information is represented, is the notion of visual memory: if the image can not be maintained securely ‘in the head’, then it is unlikely that it will be rotated accurately or superimposed appropriately on to another mental figure.

There may, in fact, be many aspects, or cognitive sub-processes, of what is generally termed ‘visuo-spatial ability’. For example, in addition to remembering the image correctly, locating the image in space and rotating the image, there is the ability to

integrate parts of the image with one another (and foresee the consequences), rather like completing a mental jigsaw puzzle. A simple example of this is to consider two-dimensional images of (say three) cogwheels. When the teeth engage, will all the gears rotate at the same speed and in the same direction? In today's world, the ability to resolve such problems is generally described as 'mechanical ability' though it seems likely that this strand of cognitive ability evolved long before the first stone tools were shaped, for example, in visualising which direction a hunted prey animal would likely take. In a modern parody of hunting-for-food, when beaters manoeuvre game birds towards 'hunters' the beaters need to integrate information about the birds' anticipated behaviour with the kind of terrain involved and the whereabouts and likely movements of the marksmen. Despite the differences in superficial structure of the two problems (cogwheels engaging and early hunting), at a deeper level the 'visuo-spatial' elements are similar, offering an example of how skills essential to our hunter-gatherer ancestors remain desirable in a technological age.

From a functional perspective, one of the more interesting attempts to tease apart differing elements of 'visuo-spatial' ability under experimental conditions is that of Silverman and Phillips (1998), who have shown that females, in general, are superior in spatial location ability. This is in direct contrast to a substantial body of evidence which shows that, in general, males are superior in other elements of visuo-spatial ability, such as map reading, maze learning and mental rotation tasks and is interpreted by evolutionary psychologists as reflecting the historical division of labour, where males hunt and females gather whilst child minding, as is found in modern bands of hunter-gatherers. In modern bands this division of labour appears to be a useful strategy with which to address the different adaptive tasks the sexes face. However, the extent to which this division of labour existed in ancient times is unknown; what is known is that these different skills are now found differentially in men and women. This offers support for the notion that, rather than cognition being subsumed by a 'general purpose' processor, there are many different, domain specific, sub-processes. From the perspective of the specificity hypothesis, the question of most interest is which of these sub-processes is most likely to aid survival when under threat, since it is being argued that caffeine is likely to enhance survival-orientated skills.

Of particular interest to the present discussion of visuo-spatial ability is the question of whether there is a *single*, combined visuo-spatial sketchpad or *separate* visual and spatial systems (Eysenck and Keane 2002): if the latter, then caffeine may affect the two systems differently. Baddeley, in discussing the visuo-spatial scratchpad, argues that ‘The spatial system is important for geographical orientation, and for planning spatial tasks’ (1997, p. 82), which, as Brandimonte, Hitch and Bishop (1992) have argued, suggests similarities with Kosslyn’s notion of a separate spatial medium. The experimental evidence tends to support this notion: Baddeley and Lieberman (1980) report that spatial information in working memory was not disrupted by a concurrent visual task and Farah, Hammond, Levine and Calvanio (1988) report a brain-damaged patient whose performance on spatial processing tasks was far superior to his performance on judging the relative size of mental imagery animals. Most compellingly, Smith and Jonides (1997) report neurophysiological evidence from PET scans, taken during a visuo-spatial experiment, which demonstrates that regions in the right hemisphere of the brain (prefrontal cortex, premotor cortex, occipital cortex and parietal cortex) became activated during the spatial elements of the task whereas the parietal and inferotemporal cortices of the left hemisphere were activated during the visual elements of the tasks. However, as Eysenck and Keane (2002) note, visual and spatial information are often interlinked in reality and are frequently inseparable elements of a task, for all practical purposes, in everyday life.

7.1.1.1. Visuo-Spatial Ability and Object Recognition

One of the most important and useful presently available theories of visual perception in general, and object recognition in particular, is that of Marr (1982), in which an initial two-dimensional primal sketch, computed from information about light and dark areas and contours, is superseded through the addition of information about shading, depth and texture by a 2.5D sketch. The 2.5D sketch does not, however, provide a good basis for object recognition. This is because it is viewpoint-centred, viewpoint-invariant information only becoming available as the representation is developed, utilising the Gestaltists’ concepts of proximity, figural continuity and closure, into a full 3D representation of the object observed. Marr and Nishihara (1978) propose that the basic units for describing objects should be cylinders having major axes, on the basis that such a representation facilitates recognition regardless of viewpoint. This notion gains some support from the observation by Humphreys and Bruce (1989) that humans and

gorillas may be readily distinguished by the relative lengths of the axes of the segments corresponding to arms and legs: we have short arms and longer legs whereas the reverse is true for gorillas. Biederman (1987), however, extending the work of Marr and Nishihara, advocates geons as the basic descriptor shapes, arguing that thirty-six different geons (such as blocks, cylinders, spheres, arcs and wedges) and the many different potential spatial relationships possible amongst them are sufficient to enable recognition of any object. Regardless of the precise (and currently unknowable) nature of the components of imagery in mental representation, a 3D representation permits the mental image to be rotated or flipped over, thus enabling recognition if the object is encountered at an unfamiliar orientation.

A particularly contentious issue in theories of object recognition is that of the degree to which object recognition is viewpoint-invariant or viewpoint-dependent. Biederman (1987), for instance, argues that ease of recognition is not affected by the observer's viewpoint, whereas Tarr (1995) argues that changes in viewpoint reduce the speed and accuracy of object recognition. Phinney and Siegel (1999) conclude that viewpoint-invariant theories typically assume that object recognition is based on stored three-dimensional images whereas viewpoint-dependent theories assume multiple stored two-dimensional representations. A series of ingenious experiments in which random-dot patterns, some of which contained only two-dimensional clues and others only three-dimensional clues, which were presented to participants, demonstrated that object recognition could be supported by either, that is, that there is stored three-dimensional representation of objects. Further work by Tarr and Bulthoff (1998) reveals that viewpoint-invariant mechanisms are used when making general between categories judgements and viewpoint-dependent mechanisms for making finer judgements within category. This makes intuitive sense, since it is easier and quicker to distinguish between a cat and a bird than between types of cat or types of bird. Viewpoint-dependent recognition is also used when objects that are visually (though not necessarily conceptually) similar are to be discriminated (Tarr and Bulthoff 1998). These notions are important both to the understanding of object recognition and to performance on tests of visuo-spatial performance, since mental rotation is almost invariably a component of such tasks.

7.1.2. Caffeine's Effects on Visuo-Spatial Ability

Since it has been argued that object recognition is crucial to survival, the hypothesis that caffeine ingestion enhances object recognition merits attention. One way of addressing this hypothesis is to consider caffeine's effect on mental rotation, since the ability to rotate mental representations is integral to the process of object recognition. The ability to rotate mental representations is generally examined in cognitive psychology through the framework of visuo-spatial ability, as is the ability to locate an object in space, also seen as salient to survival chances, so caffeine's effect on differing tests of visuo-spatial ability is evaluated here.

From the theoretical perspective of the specificity hypothesis it is easy to accept the notion that an enhanced ability to see that 'something', rather than 'nothing', is there would have adaptive potential, but it may be less easy to speculate on how enhanced visuo-spatial ability would increase the chances of survival and successful reproduction. However, it has been argued that caffeine ingestion produces a greater readiness for action so it is, perhaps, feasible to argue that enhanced visuo-spatial ability might improve survival chances in an escape and attack scenario, for example. In addition, it is possible to speculate that better visuo-spatial skills may have improved the chances of finding food and water when our ancestors lived as hunter-gatherers. Lack of food and water or attack by hostile forces both represent serious environmental threats to survival, which may be ameliorated by enhancement of either, or both, of the aspects of visuo-spatial ability posited by Pavio. Hence the question presently addressed is whether visuo-spatial ability is affected by the increased readiness for action, which it is argued follows caffeine ingestion.

7.1.3. Visuo-Spatial Empirical Studies

There are relatively few published studies on caffeine's effects on spatial or visuo-spatial ability. This may be because researchers have not addressed these questions previously or, given the 'significant findings' publication bias, it may be that the questions have been addressed but few significant effects have been found. However, Haskell, Kennedy, Wesnes and Scholey (2005) report caffeine improving performance in a spatial memory accuracy task, in which 48 adults served as participants, whereas Scott, Coyne, Johnson, Lausted, Sahota and Johnson (2002) report no effect of caffeine on spatial skills and Ruijter, Ruijter, Snel and Lorist (2000) found no specific effects of

caffeine on spatial-selective attention, but rather a general facilitating effect on perceptual processing. With regard to comparative studies, Prediger, Pamplona, Fernandes and Takahashi (2005) report that caffeine improves spatial learning deficits in the spontaneously hypertensive rat (which is used as an animal model of attention deficit hyperactivity disorder) and Angelucci, Cesario, Hiroi, Rosalen and Da Cunha (2002) report that caffeine significantly improves performance in rats on the spatial version of a water maze task.

A plausible explanation for the contradictory findings reported above, in addition to differences in dose of caffeine and in experimental procedures, is that the tasks, all of which are placed under the general heading of visuo-spatial ability are in fact testing different aspects of this cognitive skill. In an attempt to further understanding of the area, particularly in relation to attempting to tease apart the ‘imagery’ (being able to ‘see’ the image in one’s head) ‘visual memory’ (being able to maintain the image accurately in one’s head) ‘rotational’ (being able to rotate the image mentally), ‘spatial’ (locating the image in mental space) and ‘integrative’ (fitting parts of the given image, or of mentally created images, together) components of visuo-spatial ability, caffeine’s effects on four tests of visuo-spatial ability are assessed. Without facilities to monitor the working brain it is difficult, to the point of speculative, to disambiguate the underlying components of the tasks and the following taxonomy is open to dispute. All tasks are presumed to involve ‘visual memory’. As described below, the tasks test all the elements of visuo-spatial ability referred to above.

In experiment 6 participants carry out a computer-generated version of Cooper and Shepard’s (1973) mental rotation task, in which upper case letters, such as ‘R’, are presented at different angles in either ‘normal’ or mirror image ‘reverse’ form, the task being to identify the ‘normal’ form. This mental rotation task is considered to be largely dependent on ‘rotation’ and the load on ‘visual memory’ to be light, since the shapes of familiar, upper case letters are over-learned in our society.

Experiment 7 comprises a computer-generated partial replication of Pylyshyn’s 1979 study in which a diagrammatic, two-dimensional (unfamiliar) shape is seen on one side of the screen, whilst the other side shows one or more potential subcomponents of the first shape. The task is to decide whether the smaller shape(s) on the right of the screen

(some of which may require rotation) will ‘fit in’ to the larger shape on the left of the screen. This test is considered to assess mainly visual integration in a two-dimensional context and may, or may not, require a degree of mental rotation.

In experiment 8, participants carry out a paper and pencil task from the spatial section of the GAT 2 (General Ability Tests 2) (ASE 1999), in which a drawing of a three-dimensional shape (e.g. a cube) has been unfolded and laid flat, like a piece of paper. The task is to decide how many of four three-dimensional shapes presented could be made from the two-dimensional, flat pattern shown. This task is considered to require three-dimensional spatial and imagery skills, in addition to a degree of integrative and mechanical skill.

In experiment 9, participants complete another paper and pencil task, the ‘spatial ability’ subtest of the Power and Performance Measures (PPM) test battery (Test Agency 1996). Participants are asked to consider two squares, A and B, in which a line or lines have been drawn. The task is to rotate square A on to what was its left side, to flip square B about its axis and then superimpose one square on top of the other, creating a completely new figure. This has the effect of creating ‘spaces’ and the task is to report the number of spaces made. Although two-dimensional, this task is considered to tap all the constituent elements of visuo-spatial skill, as hypothesised above, that is, visual memory, imagery and mental rotation, the rotational and spatial aspects of the task being tapped by the need to identify the number of ‘spaces’ made. It is accepted that the categorisation of the constituent elements of the above tasks of visuo-spatial skills may be contentious.

The problem of attempting to designate a particular task as involving a larger ‘spatial’ or ‘imagery’ component is exacerbated not only by the extent to which visual memory is required by a task but also, it is suggested, by the type of memory representation required. The PPM task described above, though complex, may be considered to invoke procedural memory, in that an individual with good imagery skills would theoretically be able to describe each stage of their thinking, mentally ‘drawing’ the new shapes at each step. Arguably, the GAT 2 task, in which the individual must fold ‘mental paper’ into new 3D shapes for comparison with other drawn 3D shapes has a declarative element, which may not be so readily available for inspection. Although it has been

argued that there is a greater memory load in the PPM test used here than in the other tests of spatial ability, 'memory load' may be too gross a distinction to be especially useful, since within the present paradigm it is not possible to distinguish between different kinds of visual memory. It is feasible to suppose that caffeine may affect different kinds of memory differentially, as it may affect all the sub-processes presumed to underlie visuo-spatial ability to greater or lesser extents. For example, when examining the effects of caffeine on rats' ability to complete the water maze task, Angelucci et al. (2002) report that caffeine administered before rats were trained had no effect on performance but that caffeine administered immediately after training showed a significant effect on the rats' ability to negotiate the maze. The authors interpret their findings to mean that whilst caffeine has no effect on memory acquisition, it does have an effect on memory retention. The hypothesis being addressed is that there will be no significant differences between caffeine conditions on performance on any of the four different tests of visuo-spatial ability described above.

7.2. Experiment 6: Caffeine's Effects on Mental Rotation Utilising Cooper and Shepard's Task

7.2.1. Introduction

On the basis that the further an image needs to be rotated before a response can be chosen the longer the response time, previous studies of mental rotation have concluded that internal representations of images are treated much as an actual image is (Cooper and Shepard 1973; Shepard and Metzler 1971). Shepard is credited with beginning the systematic study of rotating mental images, using the paradigm of an upper case letter which was either 'normal' or 'reversed' at different orientations. Participants were slower to respond to mirror images than to normal stimuli and the further the letter was rotated from upright, the slower the response. Shepard used a variety of other stimuli, such as three-dimensional asymmetrical figures made of blocks and complex irregular polygons. This paradigm has been extended by Tarr and Pinker (1989) who used two-dimensional pictures of three-dimensional block-like forms, where the task was to decide whether a given form was the original form rotated or a different form, and by Cohen and Kubovy (1993) who utilised a similar paradigm to Cooper and Shepard's using digits rather than letters. Corballis and McLaren (1982), using a rotating disc, induced rotational after-effects and found that reaction times to a rotation task were increased when the after-effects were in the opposite direction to that of the mental

rotation required by the task. In the present study, a computer-generated version of Cooper and Shepard's original 'letter' experiment is utilised and caffeine's effects on both accuracy and speed are assessed.

7.2.2. Method

7.2.2.1. Design

The design of this study is a mixed (within-between), double-blind experiment, where caffeine or no caffeine constitutes the between subject independent variable, times 1 and 2 the within subject independent variable, correct identification of a letter shape as either 'normal' or 'reversed' serves as one dependent variable and RT as the second dependent variable.

7.2.2.2. Participants

An sample of 56 first year undergraduates reading for social science degrees (criminology, policing or sociology), 76% female, aged 18-24, mean age 23.4 years, acted as participants. All participants reported being normal, moderate, tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision. Participants had been requested to abstain from ingesting caffeine for 12 hours prior to the experiment and confirmed that they had done so.

7.2.2.3. Materials

The experiment generator used is SuperLab, which provides a partial replication of Cooper and Shepard's original experiment, utilising normal and reverse versions of the upper case letters F, L and R at orientations varying between 0 and 180 degrees. The programme records error, self correct, correct and response time in milliseconds.

7.2.2.4. Procedure

After classification details had been collected and the nature of their participation explained, the participants were allocated randomly to caffeine or no caffeine condition. The procedure was then carried out double-blind. Participants took part in the mental rotation task, completing approximately 100 trials each (following 30 practice trials) providing time 1 baseline measures. Participants were then administered a mug of caffeinated or decaffeinated coffee naturalistically, adding milk and sugar to taste.

Twenty minutes later participants returned and again carried out the mental rotation task, these measures providing time 2 data.

7.2.3. Results

Since data in error and response time were collected together, it is appropriate to consider them together. At first glance there appears to be a substantial difference between the caffeine conditions error time 2, the caffeine condition producing a mean of just over 13 errors, whilst the decaffeinated condition shows a mean of 23 errors. In addition, the caffeine condition shows a markedly lower standard deviation than the decaffeinated condition. This pattern is rather different from that seen in the response time data, where although the caffeine condition has again performed better and has a narrower standard deviation than the decaffeinated condition, the difference of approximately 80 milliseconds in both the mean and standard deviation is not so striking as the difference in error rates. Descriptive data are summarized in Table 7-1 below.

Table 7-1: Mean and Standard Deviation for Both Number of Errors Made and RT (in milliseconds) to a Mental Rotation Task at Time 2 Across Caffeine Conditions

Caffeine/Decaffeinated Condition		Mean	Standard Deviation	N
Number of Errors	Caffeine	13·60	10·72	30
	Decaffeinated	23·15	15·55	26
	Total	18·04	13·91	56
RT in Milliseconds	Caffeine	1119	341	30
	Decaffeinated	1206	431	26
	Total	1159	384	56

Interesting though the above data are, inevitably the question arises as to whether the differences found in error rate are due to some inherent difference between the two groups or whether the difference found may be attributed to the independent variable, caffeine. Since two independent variables, one between subject (caffeine condition) and one within subject (times 1 and 2), and two dependent variables, number of items completed and number of correct identifications, are being considered, the appropriate

form of analysis is considered to be a mixed, multivariate analysis of covariance. In effect, 'time' is treated separately as a within subject independent variable on number of items correctly identified and number of items completed. After the usual preliminary checks were carried out to ensure no violations of the assumptions of normality, linearity, homogeneity of variance, homogeneity of regression slopes and reliability of the covariate, a Wilk's Lambda value of 0.803 indicates a significant difference between groups, $p < 0.003$, indicating a main effect of caffeine. The next question of interest is whether caffeine affects both dependent variables equally, or whether one dependent variable is affected more than the other. In this case, the latter proves to be the case, the between subject analysis showing no effect of caffeine on RT [$F(1,54) = 0.709$, $p = 0.404$] but a significant effect of caffeine on number of errors made [$F(1,54) = 7.323$, $p < 0.009$]. When considering a number of separate analyses at the same time, it is considered good practice to adjust the alpha level by the number of analyses carried out simultaneously (Bonferroni adjustment), in order to minimize the possibility of committing a Type 1 error (falsely accepting the hypotheses as correct). When this is done and the usual alpha level divided by the number of dependent variables, in this case two, (number of errors and response time), giving a new alpha level of 0.025, it is found that the observed level of probability, 0.009, is well outside this range and it is therefore safe to conclude that in this experiment caffeine has had a significant effect on reducing the number of errors made in a mental rotation task. In fact eta squared suggests that 12% of the variance in the number of errors made may be attributed to caffeine whereas only 1.3% of the variance in RT may be attributed to caffeine conditions.

7.2.4. Discussion

According to these data caffeine significantly reduces number of errors in a mental rotation task, whilst not affecting RT. This finding is of interest in that it may be seen as tentative support for the specificity hypothesis and, if these findings are replicated, may have substantial implications for a number of professions where accuracy in spatial ability is critical. This finding may be relevant to the debate about the nature of visuo-spatial ability, where it has been argued that the ability to rotate objects mentally is separate from spatial ability *per se*. This question is considered not only to have inherent interest but to have particular relevance to the specificity hypothesis : if these two different abilities underlie what is usually termed visuo-spatial ability, it is

conceivable that one or other of the abilities may have greater adaptive value than the other. For example, spatial memory may be important in remembering where to find food or water or the migration routes of prey animals and spatial ability may be important in planning sorties against, for example, a hostile tribe of humans. However, none of these scenarios captures the immediacy of the survival response as articulated by PVT and so they are judged not to be especially compelling.

Is there, on the other hand, a more convincing reason to consider that mental rotation may have adaptive value? It is argued here that the answer to this question is a definite affirmative. Object recognition is a critical cognitive process, without which we would not be able to make any visual sense of the world about us, and the notion of size and shape constancy, despite variations in the size and shape of retinal images, is well established in the literature. However, for object recognition to be maintained at whatever angle or orientation the object is seen, mental rotation must occur: that is, it is being argued that mental rotation is an integral sub-process of object recognition. If this premise is accepted, it becomes clear why mental rotation is a cognitive attribute which has survival value. Our ancestral forefathers, when surveying the near distance, would have needed to make quick decisions as to whether a particular shape seen represented an irregularly shaped rock, or bush, on the one hand, or a concealed predatory animal, or human, on the other. Mental rotation is essential to the correct recognition and categorisation of the ambiguous shape and correct recognition and categorisation would be very likely to aid survival. Critical to this argument is firstly the notion that mental rotation and spatial location are two separate cognitive attributes and secondly that caffeine affects the former, which is seen to be more obviously adaptive, whilst not affecting the latter. In addition the cognitive load with respect to visual memory is seen as potentially important, since some tests of 'spatial ability' are clearly more demanding of visual memory than others. In an attempt to evaluate these ideas, caffeine's effects on further tests of visuo-spatial ability are assessed.

7.2.4.1. Strengths and Limitations of the Study

The within-subject element of the analysis of covariance controlling for individual differences and practice effects, double-blind procedures and computerised measurements may be considered strengths of these experiments. On the other hand, the

ad hoc undergraduate samples must be considered a weakness, since this reduces confidence that the findings may be extrapolated to other groups.

7.3. Experiment 7: Caffeine's Effects on Pylyshyn's Task

7.3.1. Introduction

The experiment described above is considered to have a high mental rotation component, to place a low demand on visual memory, since the shape of upper case letters of the alphabet were well known to all participants, and to have virtually no 'location in space' component. It is considered that the present experiment, a partial replication of Pylyshyn's (1979), again has a high mental rotation load and little 'location in space' component, but differs considerably from Cooper and Shepard's task in that it places a heavier load on visual memory, requiring the identification of 'true', 'mirror' and 'foil' components of complex figures.

The impetus for the development of Pylyshyn's original experiment was the debate as to whether visual images could be reduced to propositional representations or utilised a different, analogue structure, through which the visual image is mentally reconstructed in the mind. In the 1970s the consensus was that mental imagery is largely supported by analogue processing, although Pylyshyn argued that much of the data being used to support this hypothesis showed evidence of propositional cognitive operations. In order to test these ideas, he developed stimuli, which consist of figures of varying complexity, 'true' subfigures, 'false' mirror images and 'foils' (not subfigures). Only by mentally rotating the subfigure (by 0, 35, 70 or 105 degrees) could a decision be made as to whether a subcomponent was 'true', 'false' or 'foil'. In his original experiment Pylyshyn used 16 participants, concluding that the factors affecting mental rotation are too numerous and complex to be supported only by analogue processing and arguing that the speed of mental rotation is a function of practice, the intrinsic properties of the stimulus (e.g. complexity) and the nature of the comparison task. The Cooper and Shepard and Pylyshyn tasks are similar in that participants need to maintain mental representations of two separate images during the tasks: a normal and rotated letter in the Cooper and Shepard task and the 'complete' stimulus together with a subcomponent which may or may not, when rotated, fit into the 'complete' shape in the Pylyshyn task. In addition, the shapes in the Pylyshyn task are irregular, variously complex and previously unknown to the participants. In the Cooper and Shepard experiment the

stimulus may readily be categorised as, for instance, ‘a capital letter R’, which is presumably easy for most normals to remember, whereas the Pylyshyn shapes, which consist of complex geometric shapes, are much harder to describe and categorise. Even when they are inspected physically, rather than mentally, and both the ‘complete’ and subcomponents are broken down into geons, problems of remembering and representing precise angles and relationships remain. Though it is presently thought unlikely that mental images are coded in words, a brief reflection on the relative difficulty of verbally describing and categorising a stimulus from the Cooper and Shepard experiment, compared with the difficulty of verbally describing and categorising a stimulus from the Pylyshyn experiment makes the difference between the tasks clearer.

As far as survival is concerned, it seems plausible to assume that general categorisations, such as ‘living thing’ versus ‘inanimate object’ or ‘natural feature that is stable’ versus ‘natural feature that is unstable’ are sufficient to indicate a primary level of threat and hence are made fastest while second order within category comparisons, such as what kind of tree is seen, follow (Grill-Spector and Kanwisher 2005). It seems likely therefore that, when considering performance on visuo-spatial tasks, most of which require comparison of one stimulus with another (usually involving rotation of one or both of the stimuli), differences in levels of categorisation will have an effect on rotation speed and/or accuracy of identification. In Cooper and Shepard’s task, the categorisation element is straightforward (‘is the letter normal or reversed?’) and may be seen as an example of within category identification. Within category decisions are responded to more slowly than between category decisions, presumably because it is generally more adaptive to know ‘what’ rather than ‘precisely what’ is in the visual field. In the Pylyshyn task there is no obvious way of categorising either ‘complete’ or ‘subcomponent’ stimuli. Since the subcomponent probe may be a ‘part of’, but is not obviously a ‘type of’ the ‘complete’ stimulus figure, it may be that this task is responded to as a between, rather than within, category identification.

Since faster visual identification may well be adaptive (both in the sense of avoiding predators and catching prey) it may be that stimuli reminiscent of threat in the physical world will elicit faster response times than stimuli (such as an upper case R) which have no obvious relationship to danger in the everyday world. Given the human imperative to impose meaning on the slenderest of visual information, it is feasible to suppose that

some of the sharply angular figures used by Pylyshyn may coincidentally trigger mental connections with notions of ‘sharply pointed’ or even ‘blades’, ‘knives’ and ‘axes’. If this is the case, evolutionary psychology would suggest that such images be responded to faster than other non-threatening images and the specificity hypothesis would suggest that caffeine will elicit a still faster response to any image perceived as potentially dangerous. On this basis, it is feasible to speculate that although caffeine ingestion did not produce a significant difference in RT on the Cooper and Shepard rotation task, it may do so on the Pylyshyn rotation task.

7.3.2. Method

7.3.2.1. Design

The design of this study is double-blind, mixed (within-between) experimental, where caffeine condition constitutes the between subject independent variable, times 1 and 2 the within subject independent variable and response time in milliseconds the dependent variable.

7.3.2.2. Participants

An *ad hoc* sample of 29 undergraduate students, 72% female, age 18-31, mean age 25.2 years, served as participants. All participants reported being normal, moderate, tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision. Participants had been requested to abstain from ingesting caffeine for 12 hours prior to the experiment and confirmed that they had done so.

7.3.2.3. Materials

The experiment-generator used is SuperLab, which provides a partial replication of Pylyshyn’s original experiment, utilising figures, ‘true’ subfigures, ‘false’ mirror images and ‘foils’, as seen in appendix x.

7.3.2.4. Procedure

After classification details had been collected and the nature of their participation explained, the participants were allocated randomly to caffeine or no caffeine condition. The procedure was then carried out double-blind. Participants took part in the Plyshyn task, completing one practice trial followed by approximately 135 trials each (64 ‘true’,

64 ‘mirror’ and 7 ‘foil’ figures) providing time 1 baseline measures. Participants were then administered a mug of caffeinated or decaffeinated coffee naturalistically, adding milk and sugar to taste. Twenty minutes later participants returned and again carried out the Plyshyn task, these measures providing time 2 data.

7.3.3. Results

Response time is considered in Table 7-2. Prior to caffeine ingestion participants in the caffeine group were slightly slower than participants in the decaffeinated group. By time 2 the difference between the two conditions has reduced by 100 ms but there is still very little difference in the means across conditions, although the spread of scores is much greater in the caffeine than in the decaffeinated condition at both test times. In both conditions RT means are lower and standard deviations less spread than at time 1.

Inferential analysis (mixed ANOVA) of the response time data indicates a statistically significant difference in performance between time 1 and time 2 [$F(1,27) = 36.9, p < 0.001$]. Most of the improvement in performance is presumed to be due to a practice effect and a value of 0.578 for partial eta squared suggests that over half of the variance in the scores between time 1 and time 2 may be attributed to this. There was no effect of caffeine on this task.

Table 7-2: Mean and Standard Deviation for RT (in milliseconds), Pre and Post Caffeine Ingestion, to Pylyshyn’s Test of Visuo-Spatial Ability

Caffeine Condition	Mean RT in Milliseconds	Standard Deviation	N
RT1 Caffeine	7906	4883	12
Decaffeinated	5750	2630	17
Total	6642	3806	29
RT2 Caffeine	5323	4432	12
Decaffeinated	3273	1176	17
Total	4121	3036	29

7.3.4. Discussion

According to these data, caffeine ingestion has no effect on performance on Pylyshyn's visual integration task: this may be because too few participants were tested (only just over half the number who completed the mental rotation task described above) to show an effect, or it may be that there simply is no effect of caffeine on this task. Overall the latter conclusion seems preferable on the grounds of parsimony, since the processes inferred to underlie this task do not obviously link to faster object identification and categorisation. The notion that some shapes may be perceived as blade or knife-like and hence threatening was not supported by discussion during the participants' debriefing.

7.3.4.1. Strengths and Limitations of the Study

A strength of this experiment is the fact that it was computer generated and hence images were presented randomly and measurements taken precisely, without risk of human error. Also the participants were allocated to caffeine or control condition randomly and the procedures carried out double-blind, which militates against social desirability and experimenter effects. A limitation is that the participants consisted of a small *ad hoc* sample of undergraduate students, although the within subjects element of the design means that each participant provided two sets of data, effectively doubling the sample size and the covariant element of the design that individual differences are controlled for.

7.4. Experiment 8: The Mental Generation of Three-Dimensional Irregular Shapes

7.4.1. Introduction

With reference to the discussion of whether there is a single visuo-spatial sketchpad or separate visual and spatial abilities, Lohman (1988) asserts three major components to visuo-spatial ability: firstly, spatial relations or rotation, which involves the mental rotation of a simple stimulus; secondly, spatial orientation, which requires judgements as to how a display would look when seen from a different viewpoint; and thirdly, visualisation, which involves the mental manipulation of complex stimuli, such that parts of the stimuli change their positions relative to each other. Lohman also questions whether it is possible to identify the underlying sub-processes involved in visuo-spatial ability, since individuals may use different strategies when addressing the same question and people flexibly, frequently and idiosyncratically switch strategies between and within question types (Kyllonen, Lohman and Woltz 1984). Lohman argues further

that many complex visualisation questions may be partially, if not entirely, solved through non-spatial reasoning processes, which may explain why such tests often load highly on general intelligence or reasoning.

However, there does seem to be some degree of consensus on what distinguishes individuals with good spatial ability from those with good non-verbal reasoning ability. Carpenter and Just (1986) and Lohman (1988) argue that 'high spatial' individuals are better able than others to create, retain and transform mental images that preserve the shapes and relative proportions of objects. Lohman argues that it is the quality of the mental image which is the key element of spatial ability, and that transforming or manipulating a previously seen image (which is seen as central to spatial ability) is in fact merely a way of assessing the quality of the mental image. Hence it is argued that using tasks which force the participant to *construct* mental images in order to answer the problem, as opposed to merely remembering images or solving the problem using reasoning, is crucial. The International Directory of Spatial Tests (Eliot and McFarlane-Smith 1983) reveals two generic question types most likely to tap encoding, rotation and comparison; 'paper formboard' tasks, which are two-dimensional, and 'surface development' tasks, which involve imagining the result of folding up a flat pattern into a three-dimensional representation of an object. In the present experiment, GAT 2 is considered a test of three-dimensional spatial ability, as line drawings of flattened pieces of paper are shown, which are to be folded mentally to match particular shapes. The shapes chosen are irregular, with a black mark on one side whilst the other side of the paper is shaded. The overall complexity of the shapes, together with the need to locate the shaded and marked sides correctly, is such that the authors consider it very unlikely that correct answers may be obtained through verbal coding and that spatial processing is virtually inevitable when reaching a correct solution (Smith, Whetton and Caspall 1999).

The original four General Ability Tests were devised by staff of the National Foundation for Education Research in 1988 in response to a perceived need by employers. The need for a test of spatial ability, in particular, was identified for situations where correct anticipation of how things will look when transformed in some way carries a high premium. For example, in the engineering and construction industries, errors of judgement in spatial ability are likely to result in waste of time and

materials and possibly put workers at risk, so it is important to assess employee ability to create accurate visuo-spatial images which may be manipulated and compared with an original image. With this in mind, the GAT 2 Spatial Test, consisting of line drawings of a flattened shape (analogous to a piece of paper) which may be folded to form a three-dimensional shape, was developed. Four such three-dimensional shapes are shown below the main figure and the task is to indicate which of these four shapes may be made from the original, flattened shape.

7.4.2. Method

7.4.2.1. Design

A mixed (within-between), double-blind experimental design is utilised, caffeine serving as the between subject independent variable, 'time' as the within subject independent variable and accuracy and RT scores as the dependent variables.

7.4.2.2. Participants

An *ad hoc* sample of 26 graduate students, 72% female, age 21-46, mean age 31.7 years, served as participants. All participants reported being normal, moderate, tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision. Participants had been requested to abstain from ingesting caffeine for 12 hours prior to the experiment and confirmed that they had done so.

7.4.2.3. Materials

The GAT 2 (General Ability Tests 2) Spatial Test (ASE 1999) is used, a copy of which is included in appendix xi. This is a paper and pencil test and was administered in accordance with test originator's instructions.

7.4.2.4. Procedure

After classification details had been collected and the nature of their participation explained, the participants were allocated randomly to caffeine or no caffeine condition. The procedure was then carried out double-blind. Participants took part in the timed test, providing baseline measures (time 1) of ability on this test. Participants were then administered a mug of caffeinated or decaffeinated coffee naturalistically, adding milk

and sugar to taste. Twenty minutes later participants returned and again carried out the GAT 2 spatial task, these measures providing time 2 data.

7.4.3. Results

As far as number of correct identifications is concerned at time 1, before ingestion of any drink, the decaffeinated condition shows a slight, non-significant, superiority in number of correct identifications over the caffeine group. By time 2, 20 minutes after drink administration, a clear practice effect is evident, both conditions improving their scores. However, there is no obvious difference in levels of improvement of performance between caffeine conditions, the caffeine condition improving by a mean of just over 3 correct identifications and the decaffeinated condition improving by a mean of just over 4 correct identifications, with no marked changes in relative standard deviation. Table 7-3 summarizes these effects.

Table 7-3: Mean Number of Correct Identifications on the GAT 2 Test of Spatial Ability, Pre and Post Caffeine Ingestion

Caffeine Condition	Mean	Standard Deviation	N
Number of Correct Identifications at Time 1			
Caffeine	8.82	7.29	11
Decaffeinated	10.80	12.63	15
Total	9.96	10.56	26
Number of Correct Identifications at Time 2			
Caffeine	12.09	10.37	11
Decaffeinated	15.27	14.41	15
Total	13.92	12.73	26

When considering the second dependent variable, number of items completed, a not dissimilar pattern emerges. Pre caffeine ingestion, the slight non-significant superiority in performance, on this measure, is again with the decaffeinated group, but the relative differences between the two groups, of approximately 5 items attempted, remains the same pre and post caffeine ingestion. A practice effect is again evident, with both groups completing a mean of five more items than at time 1, neither group showing an advantage, as shown in Table 7-4.

Table 7-4: Mean Number of Items Completed on the GAT 2 Test of Spatial Ability, Pre and Post Caffeine Ingestion

Caffeine Condition	Mean	Standard Deviation	N
Number of Items Completed at Time 1			
Caffeine	48.36	20.81	11
Decaffeinated	53.33	15.75	15
Total	51.23	17.84	26
Number of Items Completed at Time 2			
Caffeine	60.18	13.86	11
Decaffeinated	65.80	16.35	15
Total	63.42	15.32	26

Since baseline measures were taken at time 1, before coffee was administered, and since two dependent variables are being considered, error rate and RT, it is appropriate to utilise multivariate analysis of covariance. After the usual preliminary checks were carried out to ensure no violations of the assumptions of normality, linearity, homogeneity of variance, homogeneity of regression slopes and reliable measurement of the covariate, a Wilk's Lambda value of 0.977 indicates no significant difference between caffeine groups, $p = 0.780$. However, when considering the within subject variable of 'time' on number of correct identifications, Wilk's Lambda is found to be 0.147, $p \leq 0.001$ and the effect of 'time' on number of items attempted shows Wilk's Lambda to be 0.258, $p \leq 0.001$. Both these observed levels of probability are well outside a Bonferroni adjusted alpha of 0.017, so it is clear that 'time', or perhaps more accurately, the inferred greater level of skill elicited by practice, has a significant effect on performance on visuo-spatial ability, as defined by scores on the GAT 2 Spatial Test. An inspection of the values of eta squared indicates the effect size of specific independent variables on performance and it is seen that the degree of variance which may be attributed to caffeine on correct identifications at time 2 is 0.022 and on number of items completed at time 2 is 0.015, suggesting that less than 2% of the variance in these scores is due to caffeine's effects. In contrast, eta squared for the effect of 'time' on number of correct identification at time 2 is found to be 0.775 and on number of items completed at time 2 is 0.466, indicating that 78% and 47% respectively of

variance in performance at time 2 may be attributed to levels of performance at time 1. The most arresting aspect of these data would seem to be the effect of time1/time 2 practice.

7.4.4. Discussion

With regard to this task, the General Ability Test 2 Spatial Test, the lack of any significant differences between the caffeine group can be seen as further tentative support for the specificity hypothesis, since the argument is not that caffeine enhances visual perception *per se* but rather that it enhances those aspects of visual perception that are critical under perceived threat. Although this task utilizes some of the processes inferred to underlie object categorization and recognition, a major part of the task is to decide how many of four three-dimensional shapes could be made from an identified two-dimensional sheet, a useful integrative and mechanical skill, which is probably not invoked in everyday object recognition. Hence the effects of caffeine ingestion can be argued to be specific.

A major criticism that may be made of the above study is the very low number of participants and the unequal numbers of participants across caffeine conditions. Both these unfortunate events were caused by circumstances beyond the control of the experimenter and the initial intention was to rerun the experiment with a more substantial sample: time constraints precluded this course of action. Failure of a participant to engage with a task, previously allocated and agreed to, is one of the challenges of carrying out research. Attrition from seasonal influenza is unfortunately, another. However, the fact that eta squared suggests that less than 2% of the variance of the dependent variable scores may be attributed to caffeine's effects militates against the possibility that a larger sample might reveal an effect of caffeine: a more plausible conclusion is that caffeine does not affect performance on the GAT 2 Spatial Test.

Without the benefit of brain scanning equipment, the degree to which any set of tests elicits and evaluates 'spatial' rather than 'visual' aspects of cognition is purely speculative. The GAT 2 is described as 'spatial' rather than 'visuo-spatial' by the author but, since it is necessary to rotate items mentally in order to answer the questions posed, it is not clear on what basis this decision was made. In addition, the GAT is the only one of the three visuo-spatial tests carried out so far, all of which rely on line drawings, to

offer three-dimensional rather than two-dimensional stimuli and it may be that dimensionality is an important element of visuo-spatial skill and, in this study, a potentially confounding variable.

Consequently it was decided to pursue the attempt to disambiguate both the nature of visuo-spatial ability and caffeine's effects on this aspect of cognition through the use of an alternative measure of visuo-spatial skill, which again involves dimensionality.

7.4.4.1. Strengths and Limitations of the Study

Weaknesses of the above study include the relatively small number (26) of participants and the fact that participants were primarily female. However, the design of the experiment (between-within) goes some way to alleviate the effects of a small sample size, since all participants provided two sets of data. A strength of the experiment is that the task used is one that is widely used in psychological research.

7.5. Experiment 9: The Generation of a Novel Mental Image, Using the PPM Spatial Ability Test

7.5.1. Introduction

In this experiment scores on the Spatial Ability Test of the (PPM) (Test Agency 1996) is used as the dependent variable, since the task appears to incorporate mental rotation, mental location in space and visual memory to a greater extent than any of the previous tests of spatial ability. The development of the PPM was influenced by the Differential Aptitude Tests (Bennett, Seashore and Wesman 1973), which distinguished between 'ability' ('what an individual can do now and may be able to do after experience and training') and 'aptitude' (an individual's 'potential to acquire an ability with training'), as defined by Barrett (1991 p. 9). In the PPM, according to Barrett, 'power' means reasoning, to which prior knowledge contributes very little, whereas 'performance' relates to and is largely influenced by prior experience. The PPM test of spatial ability involves the reversal and rotation of an original mental image. Specifically, it requires participants to rotate and turn over ('flip') two-dimensional shapes, in order to be able to 'see' the shapes from the other side, as well as to hold these new representations in visual memory in order to superimpose one on the other and report the new representation. Hence this test appears to contain elements from all three previous tests of spatial ability.

7.5.2. Method

7.5.2.1. Design

A between subject, double-blind experimental design is utilised, caffeine serving as the between subject independent variable and scores on the PPM test of spatial ability as the dependent variable.

7.5.2.2. Participants

An *ad hoc* sample of 42 male undergraduate students, age 19-51, mean age 27.2 years, reading for computing or policing studies degrees served as participants. All participants reported being normal, moderate, tea/coffee drinkers. None reported working shifts or suffering from a sleep disorder. All had normal, or corrected to normal, vision. Participants had been requested to abstain from ingesting caffeine for 12 hours prior to the experiment and confirmed that they had done so.

7.5.2.3. Materials

The PPM test of spatial ability is used. This is a paper and pencil test (as seen in appendix xii) and was administered in accordance with the test originator's instructions. Cans of cola containing either 124 mgs caffeine, 'high caffeine cola', or virtually no caffeine, 'decaffeinated cola', covered with sticky-backed plastic in order to conceal their contents, were utilised.

7.5.2.4. Procedure

Participants were allocated to caffeine conditions randomly. The PPM test of spatial ability was then administered 15 minutes after participants had ingested a can of cola, either high caffeine (124 mg) or decaffeinated.

7.5.3. Results

The high caffeine condition has a slightly lower mean and slightly broader distribution of scores than the decaffeinated condition. There were a number of spoiled papers, apparently due to the frustration of facing what was perceived as a difficult task, resulting in unequal numbers of participants across the two conditions, 18 in the experimental condition and 24 in the control condition, as may be seen from Table7-5.

Table 7-5: Mean and Standard Deviation for Correct Items in a Test of Visuo-Spatial Ability (PPM), by Caffeine Condition

Caffeine Condition	Mean	Standard Deviation	N
High Caffeine	4.417	4.472	18
Decaffeinated	5.217	4.117	24
Total	4.874	4.239	42

When the data are analysed inferentially there is no violation of Levene's test of error variance, the probability level being found to be 0.226. A one-way analysis of variance shows no significant difference between conditions on performance of the PPM test of spatial ability [$F(1,41) = 0.361, p > 0.05$].

7.5.4. Discussion

It became apparent during debriefing that the task of rotating one square anticlockwise, rotating a second square about its axis ('flipping it over'), superimposing the one on the other and then counting the number of 'spaces' so made, was perceived as difficult by participants. Barrett (1991) offers test statistics ($n = 558$) of a mean of 9.27 and standard deviation of 4.15, with a score range of 0 to 21. The mean score of the present sample is only a little over half of that of the Barrett sample, with a range from 0 to 14, though the standard deviations are similar. Barrett's sample is described as consisting of engineers, tradespeople (such as fitters and electricians) and pilot applicants, so it is feasible to speculate that the practical experience of Barrett's sample may have given them an advantage over the undergraduates used in the present experiment.

There are several known (and almost certainly considerably more unknown) subcomponents of the PPM spatial ability test so, even if a significant difference in performance had been found across caffeine conditions, it may have been difficult to conclude anything specific about caffeine's effects. The allocation of participants to caffeine conditions, before the test, was even and it is noticeable that fewer participants in the decaffeinated condition spoiled or ignored their test papers than did participants in the caffeine condition. Although the 'high caffeine' cola contained the caffeine equivalent of only two cups of coffee, the literature indicates that this would be sufficient to raise physiological arousal on a number of parameters and it is feasible therefore to speculate that it may have been sufficient to alter patterns of neural

regulation from a perception of 'low' to 'increased' threat. If, as may be, this increased neuroception of perceived threat shifted individuals to the lower end of fight-and-flight behaviours, the increased frustration apparent from the higher rate of spoiled papers becomes explicable.

7.5.4.1. Strengths and Limitations of the Study

A weakness of the study is that the sample size of 42, though small, is made more problematic by the uneven number of participants in each condition. The task undertaken in this experiment is widely used by occupational psychologists and so may be considered reliable and valid in and of itself, but appeared to be too complex for the sample of policing and undergraduate students to whom it was offered. A strength of the study is that it was carefully carried out under laboratory conditions.

7.6. General Discussion

Since the above four experiments investigating caffeine's effects on different tests of visuo-spatial ability were carried out under similar conditions and utilized similar participants (male and female undergraduates and graduate students), this section starts with a brief general discussion of the potential implications of the data, before going on to consider specific effects of caffeine on tests of visuo-spatial ability. A number of interesting points arise from the assessment of caffeine's effects on the four different tests of spatial ability. Firstly, although differences in spatial ability are generally considered to be innate and hence largely fixed, highly significant improvements in performance were shown by all participants across all tests at time 2 as compared with time 1. These rather striking practice effects suggest that spatial ability may be acquired through practice, at least to some degree, as opposed to being an innate ability or some aspect of non-verbal intelligence. It may be more appropriate to consider visuo-spatial ability a skill than, for example, an aspect of intelligence, and this may have a number of practical and professional implications.

Secondly, the different tasks were chosen in order to evaluate caffeine's effects on a broad range of aspects of visuo-spatial ability. It was assumed that there would be an overlap of (presently unknowable) sub-processes across the different tasks but, drawing on the theory of the specificity hypothesis, that only those elements most likely to be implicated in object identification and categorisation would be subject to the effect of

caffeine ingestion. In fact this appears to be the case, since mental rotation is clearly necessary for object identification from different viewpoints, whereas visual integration, visual memory and the ability to perform complex operations on visual images are less obviously relevant to identification and categorisation.

Thirdly, the specificity of caffeine's effects has been demonstrated again: all the visuo-spatial tasks are superficially similar and almost certainly have several sub-processes in common, yet caffeine has affected just one aspect of one task, an element, that of mental rotation, which is inferred to have particular adaptive potential. Overall the experiments on visuo-spatial ability may be seen as further tentative support for the caffeine specificity hypothesis and the adaptive value of caffeine use.

Chapter Eight

Conclusions and Implications

8.1. Introduction

In evaluating the degree to which moderate caffeine use promotes adaptive behaviours, through the ability of caffeine to elicit the mammalian threat response, a number of problems need to be addressed. Some of these problems relate to the nature of the enquiry, some to theoretical decisions taken and some to choice of particular experiments and associated procedures. First amongst these is the fact that the mammalian threat response, or response to perceived danger, or 'stress' as it is commonly called in its chronic form, is presently not fully understood, not fully documented and hence not fully testable. Similarly the effects of caffeine ingestion on brain and behaviour have been studied only on a subset of potentially susceptible perceptual, cognitive, motor and regulatory systems. Since there is much yet to be understood in these two crucial areas, it may be argued that the current undertaking is over ambitious. However, there is a clear need for greater knowledge of caffeine's effects, in terms of both theory and practice, and it is suggested that the present thesis may be seen as a small step towards this end. It is argued that the work carried out to date, which is encapsulated below, is sufficient to offer tentative support for the current thesis and to provide a clear framework within which further research may address these issues.

Despite a substantial body of research on the effects of caffeine use, no clear understanding of the psychological mechanisms underlying these effects has yet emerged. It is acknowledged that useful advances in understanding the neurochemistry of caffeine's effects have been made but, interesting and necessary though these are, they are unable to offer predictions about the circumstances in which caffeine ingestion changes behaviour, or an explanation of why this should be so. The current thesis argues that when the specificity of caffeine's effects is acknowledged and studied, the pattern of caffeine 'susceptible' behaviours is readily seen to be congruent with that of the mammalian response to threat.

Where authors have bravely attempted to summarize current research on the effects of caffeine (for example, James 1997; Snel and Lorist 1998), a great many conflicting

research findings have been found. In most other areas of research, where several thousand papers have been published on a particular topic, a nascent theory of the mechanisms involved begins to emerge. However, in the case of research on the effects of caffeine use, there is as yet more ambiguity and contradiction than clarity. Given that the general population is ingesting caffeine at higher levels and at a younger age than ever previously recorded, and that the armed forces and medical and pharmaceutical professions are using caffeine more frequently than before, the lack of a theoretical insight into caffeine's behavioural effects becomes a cause of serious concern. It is argued that the current thesis provides a theory, which is able to offer both testable hypotheses and predictive power in relation to caffeine use. It is freely acknowledged that the theory is in its early stages and that much more work is needed to support it, as is often the case with novel ideas.

A major problem in the extant literature is the fact that apparently similar tasks, behaviours, or the cognitive processes inferred to underlie them, are affected differentially by caffeine ingestion. This problem was the impetus for the present work, the aim of which was to identify a theoretical framework which would offer a reasoned argument for why some behaviour, but not other overtly similar behaviour, is sensitive to caffeine use: the specificity hypothesis.

Several psychological perspectives were considered in relation to caffeine use before it became apparent that the evolutionary perspective, underpinned by Porges' Polyvagal Theory, was the most fruitful to pursue. The notion that moderate caffeine use in healthy adults promotes adaptive behaviours is a natural conclusion from the application of the specificity hypothesis.

It is hoped that the specificity hypothesis, in relation to caffeine's effects, will provide the means to disambiguate at least some of the many conflicts and contradictions that presently exist in the caffeine literature. Differing experimental paradigms inevitably produce differing results but in most cases, over time, a consensus emerges. From the perspective of the present thesis, part of the reason this has not happened in the caffeine literature may plausibly be attributed to the fact that some research tasks, which appear superficially to be similar and are assumed to be tapping many of the same sub-processes, overlap differentially with the threat response. It is argued that tasks which

elicit components or sub-processes of the threat response are affected by caffeine whereas those which do not elicit these components remain unaffected by caffeine.

The decision to run parallel experiments, for example three card-sorts, tests of both verbal and numerical processing speed, global and local processing, two tests of field dependency, four tests of visuo-spatial ability and parallel Stroop, tasks was made in an attempt to demonstrate this specificity. In fact, the specificity hypothesis is argued to be central to the evaluation of the notion that caffeine use elicits strategies and resources which under no caffeine conditions are elicited by the perception of threat.

8.2. Summarizing the Evidence for the Specificity of Caffeine's Effects

8.2.1. Specific Effects of Caffeine Use on Physical Performance

As described in Chapter Two, prior research shows beyond reasonable doubt that caffeine's enhancing effects on physical performance are apparent in only a subset of sporting activities. A detailed examination reveals that only those physical activities which involve covering ground rapidly or long distance endurance show beneficial effects under caffeine ingestion. Without the structure of a superordinate theory this observation is merely interesting, but seen through the perspective of the specificity hypothesis, it generates predictive and testable hypotheses. Similarly, prior studies, also described in Chapter Two, have shown that caffeine reduces the experience of pain and increases the efficacy of painkilling substances, both of which would likely aid survival in a hostile environment. In summary, it is argued that these two tranches of extant evidence both support the specificity hypothesis and indicate the nature of that specificity. In effect, they offer support for the present thesis, that caffeine use aids survival when under attack or threat of attack.

8.2.2. Specific Effects of Caffeine Use on Aspects of Personality

In response to the argument that adaptive behaviours spread within populations, a survey of caffeine use amongst young people was carried out and compared with previous surveys. The data shows that young people are ingesting more caffeine than previously recorded and that caffeine ingestion starts at a much younger age, that is during childhood, than has been recorded in the past, when adolescence was seen as an appropriate time for the introduction of caffeine to the diet. More research is needed to

assess the long term effects of caffeine (mostly consumed through colas) in the diets of children.

Prior research on caffeine use and personality, as described in Chapter Two, shows no clear pattern emerging, nor any clear theoretical underpinnings linking aspects of behaviour with caffeine use. For example, one might predict that, since caffeine use increases cortical arousal in the ARAS, behaviour would shift towards introversion, which some researchers have reported, although other researchers have reported the opposite, a shift towards extraversion, and still others a shift towards higher neuroticism. The present work, however, found a strong negative correlation between Eysenck's concept of venturesomeness and level of caffeine use. From the perspective of the specificity hypothesis these effects may be explained, though since the effects are correlational any explanation is inevitably speculative.

With regard to the negative correlation of caffeine use with venturesomeness, the best way to survive may, in many cases, be simply not to put oneself at risk. Being risk averse, which likely involves avoiding strange places and contact with unknown individuals, may well have been adaptive in our ancestral past when strange places offered the potential of danger from the physical landscape, predatory animals and hostile conspecifics. Many animals, from rats and mice to *Homo sapiens* prefer to use known paths, previously proved to be safe, rather than constantly venturing out to find new routes. In addition to the safety factor, such behaviour is likely to reduce cognitive load and save time. In some circumstances, dangers may still be found today, hence the negative correlation of caffeine use with venturesomeness may be interpreted as caffeine use promoting an adaptive behaviour.

With reference to the conflicting positive and negative correlations others have found with caffeine use and extraversion, the present thesis predicts that increased arousal will lead to greater engagement of the 'social vagus' (as specified in Polyvagal Theory), which might well lead to higher scores on the sociability subscale of extraversion scales. Corr, Pickering and Gray (1995), whilst finding no link between weekly caffeine use and extraversion, did find a positive correlation between caffeine use and increased sociability and impulsivity. So caffeine use, as well as showing specific effects on the first order trait of venturesomeness, appears to be affecting other traits or subscales

within the type or ‘supertrait’ of extraversion. In order to gain a clearer picture, further work of a detailed nature is needed to establish correlations between level of caffeine use and the subscales of Eysenck’s personality factors. Only when these data are available will it be possible to make useful arguments about aspects of personality and caffeine use, which in the past appears to have been an area of some fascination to researchers.

8.2.3. Specific Effects of Caffeine Use on Cognition and Perception

Given that caffeine use increases cortical arousal, it is perhaps not surprising to find evidence of better performance on a number of cognitive-perceptual tasks after caffeine ingestion. However, the improved performance is not found across the board but is specific to a particular pattern. There may be other interpretations of this pattern available but, applying Occam’s razor, it is argued here that the interpretation in terms of caffeine eliciting adaptive behaviour is both valid and parsimonious.

A review of the research evidence put forward here indicates that, contrary to Lorist’s (1995) contention that caffeine affects input and output processes across the board, caffeine’s effects are specific to particular types of task. An attempt was made to ‘match’ three kinds of processing tasks: card-sorting, consisting of three different sorts (odd-even, median split and black-red) and both verbal and numerical processing. If caffeine’s effects were indiscriminate across input and output processes it would be expected that all, or none, of these tasks would be susceptible to caffeine ingestion, whereas in fact caffeine’s effects were found to be differential.

In the card-sort, caffeine’s effects were seen only on the natural category of odd-evenness (as opposed to the median split and colour sort). It has already been noted that categorisation is intrinsically entwined with the identification that ‘something’ is there, to the point that categorisation appears to be an integral part of object identification, hence potentially aiding threat detection. On this basis, the ability of caffeine to enable faster categorisation may be seen as a further element of support for the specificity hypothesis.

The degree to which odd-evenness is a coherent, natural category may be questioned: surely, it may be argued, this is an arbitrary concept imposed by human endeavour to

understand the universe. Apparently this is not the case, part of a number's meaning being its odd-evenness, and according to Morikawa and Newbold (2003) examples of odd-evenness abound in the natural world, for example, in geography, physics and chemistry. Morikawa and Newbold, in illustrating this, cite an English translation of the work of a nineteenth century chemist, Laurent, who states that the sum of nitrogen and hydrogen is always an even number in every nitrogenous compound, as one of several examples of the phenomenon.

If the notion is accepted that odd-evenness is a category readily found in the natural world, in a way that median splits and red-black divisions are not, then the differential effects of caffeine on these card-sorts becomes of particular interest. Categorisation is intrinsic to object identification and fast object identification is crucial to survival. It is then plausible to argue that caffeine's ability to speed categorisation is a piece of evidence to support the specificity hypothesis and further evidence that caffeine ingestion promotes elements of adaptive behaviour.

In opposition to Lorist's model of caffeine's effects, the present thesis offers no theoretical argument to suppose that numerical and verbal processing tasks would show the effects of caffeine ingestion, since it has been argued that only threat detection, stress diffusion or escape-related processes would be so affected. The fact that caffeine ingestion did not show an effect on these tasks is another strand of support for the specificity hypothesis.

8.2.4. Caffeine Use and Inferred Threat-Detection Perceptual Processes

The early identification and simultaneous categorisation of novel proximal stimuli, involving the shift from global to local processing, the mental rotation of shape and the visuo-spatial ability necessary for object identification, has the same potential to protect us from danger as it had for our ancestors. Similarly, the ability to detect quickly and accurately that 'something' rather than 'nothing' is within the visual field, that is, the ability to disambiguate figure from ground, again has adaptive potential. The fact that caffeine ingestion enhances such processes, but fails to enhance apparently similar processes which are less obviously related to threat detection, lends support to the specificity hypothesis and the notion that caffeine promotes adaptive behaviours.

The argument that caffeine ingestion speeds cognitive and perceptual processing in general is shown to be false, firstly because, within the present work, there is no effect of caffeine on two out of three card-sorts, secondly by the fact that there is no effect of caffeine on verbal or numerical processing, thirdly by the fact that caffeine ingestion enhances local processing whilst disrupting global processing and fourthly by the ability of caffeine ingestion to enhance only one of four kinds of visuo-spatial ability (though two of the four tasks had unacceptably low power). In the literature this kind of anomaly has been attributed to the notion that some tasks are susceptible to caffeine ingestion whilst others are not. The present thesis supports this notion but argues that ‘susceptibility’ to caffeine’s effects is not arbitrary but directly linked to the degree to which object identification and hence threat detection processes may be inferred to underlie the task.

Specificity, within a threat-detection paradigm, is seen when examining caffeine’s effects on figure-ground discrimination. The GEFT, which seems to be a relatively pure measure of figure-ground discrimination, since it does not involve memory for particular objects, shows an effect of caffeine ingestion whereas the PEFT, which necessitates recall of pictures recently seen, does not. Being able to discriminate someone or something partially obscured by shadows or mist, which is analogous to the GEFT task, is again consistent with a greater probability of survival, whereas memory for line drawings of objects is less obviously an adaptive behaviour.

With reference to the four experiments on caffeine’s effects on different aspects of visuo-spatial ability, caffeine again shows specific differential effects. There is a significant effect of caffeine on accuracy for the recognition of a known stimulus (upper case letters) when rotated and reversed. From an evolutionary psychology perspective, it is possible to speculate that it was important for our early ancestors to notice and become readily aware that an apparently unfamiliar shape might be, for instance, a snake hanging down from a tree or the back of a wild animal. Cooper and Shepard’s task is considered to tap the skill of mental rotation and reversal, whereas the other visuo-spatial tasks utilised are considered to tap integration, mechanical skill, imagery and location in space, or a combination thereof. This finding again suggests that the underlying process which caffeine use is enhancing in Cooper and Shepard’s task

relates more to object recognition, identification and categorisation than visuo-spatial ability *per se* and that such enhancement may be considered an adaptive behaviour.

In relation to visuo-spatial tasks in general, some criticism is valid due to the fact that samples contained both genders, which were not always evenly balanced, and some of the tasks may be considered 'male friendly'. Given the sexual dimorphism noted in the literature, it may well have been more productive to have used separate single sex samples. In most visuo-spatial tasks males' performance is superior, a notable exception being object location memory. Using an ecologically valid method where real plants were arranged in small or large arrays, Neave, Hamilton, Hutton, Tildesley and Pickering (2005) found females to be faster and more accurate than males in finding specific plants, a result which is seen as support for the Gathering Hypothesis. It would be of interest to test caffeine's effects on a location memory task, since memory location has a number of practical applications, and further work testing a wider range of visuo-spatial abilities on single sex samples is advocated.

It may be that sexual dimorphism should always be taken into account in experiments to do with visuo-spatial abilities. However, doing so is unlikely to be straightforward. The pervasive male superiority in visual-spatial ability is attributed to the hormonal influence of oestrogen, a hypothesis which was tested by Lund, West, Tian, Bu, Simmons, Setchell, Adlercruetz and Lephart (2001), when male and female rats were fed phytoestrogens. The diet reversed the normal sexual dimorphism on a visual spatial memory task. If oestrogen levels have the same effect on human participants as they do on rats, ideally levels of oestrogen should be recorded, or at the very least a record taken of the amount of foods high in phytoestrogens, for instance soya, normally consumed. However, since levels of hormones fluctuate over time for both males and females and are strongly influenced by the use of hormone-based contraception a clearer picture is likely to be difficult to ascertain and when ascertained to be atypical of normal, everyday performance.

In situations of pre-existing arousal, such as that induced by the cognitive conflict inherent in the Stroop task, caffeine ingestion is unable to increase arousal further. In Chapter Six of the current work this was demonstrated by the fact that caffeine ingestion showed no effect on performance in the newly developed Phobic Stroop test

(this finding is in line with previous research using the Emotional Stroop test), as compared with performance on the neutral Stroop condition. This suggests that anxieties about regular caffeine ingestion provoking 'jittery feelings' may be largely unfounded, although individuals with an atypical number of particular receptors may experience such feelings. In fact, since caffeine ingestion releases calcium into the blood stream, it is likely to have a calming effect psychologically, whilst preparing muscles for any action that the situation may elicit. However, it is feasible to speculate also that individuals whose body store of calcium is low (due to poor diet, a growth spurt or a metabolic disorder) may be at risk of feeling jittery if caffeine is consumed excessively. The theory of caffeine's effects on specific aspects of behaviour posits that *moderate* caffeine use in *healthy adults* promotes adaptive behaviours and it is argued that the empirical work reported here supports this premise.

8.3. Critique of Empirical Work

There is clearly much room for improvement and extension in the empirical work reported here. Since the data met parametric assumptions, analyses were carried out through a variety of parametric tests, since these are considered to be more powerful than non-parametric tests, which is seen as appropriate. However, although good research practice was adhered to in the sense that participants were always allocated to condition randomly and administered the independent variable (either coffee or cola) double-blind, the samples were not randomly selected, for pragmatic reasons. In addition, although instructions were standardized and experimental protocols as similar possible, taking account of the different procedures, all samples were *ad hoc*, consisting of undergraduate or graduate students, or serving police officers, so inevitably the extent to which any of the findings may be generalised is compromised. Gender imbalances existed in some samples, for example all the police officers tested were male, and in some of the social science student samples the majority of participants were female. A consideration of the gender of participants in tests of visuo-spatial ability is problematic, since males show superior performance on some aspects of visuo-spatial ability, whilst females show superior performance on others. Using single sex samples does not solve all problems since fluctuating hormones in both sexes affect performance, for example, lower levels of testosterone are associated with poorer visuo-spatial scores. Ethnicity was not recorded as an experimental variable, because there is no suggestion in the literature of differential effects of caffeine on different ethnic groups. In addition,

caffeine metabolism is affected by levels of female hormones, natural and artificial, which was not accounted for in the experiments reported in this thesis. Also, in some cases the number of participants due to take part in an experiment was substantially reduced, for reasons beyond the experimenter's control, so that the sample size is smaller than is desirable. Two of the most important lessons learned during the Ph. D. process for this author are, firstly the importance of carrying out prospective rather than retrospective power analyses and secondly the desirability of enrolling fifty per cent more participants than are thought to be necessary, so that when attrition occurs, for whatever reasons, the remaining sample is sufficient for purpose.

The small sample sizes in some experiments are without doubt a problem, since power analysis suggests that the small sample size would preclude an effect being statistically significant, even if such an effect existed. A finding of 'no statistically significant difference' may mean that the independent variable has no effect upon the dependent variable (in the prevailing circumstance) in which case the research question is answered satisfactorily, but on the other hand may mean that the power of the experiment is insufficient to show such an effect, in which case theory should guide subsequent action.

An example of this can be seen when considering caffeine's effects on the visuo-spatial experiments reported here. Three of the four experiments examining caffeine's effects on aspects of visual-spatial ability reported in Chapter 7, failed to show any effect. This may have been because the experimental task was too complex, such as in the PPM task where participants are asked to consider two squares, A and B, and then to rotate square A 90 degrees anticlockwise, turn square B upside down around an imaginary middle line, superimpose one of these new forms upon the other and then count the number of 'spaces' so created. There are so many sub-processes involved in this task, which may be differentially affected by caffeine, that it is not really surprising that no effect was found, despite a power β of over 0.9 and with the benefit of hindsight, the task is considered too complex to be useful in this context, particularly since it is not obviously related to threat detection.

On the other hand, Pylyshyn's task of deciding whether a novel shape can be accommodated within a target 'main' shape and the GAT task of imagining a 2D shape

cut out and folded into 3D, are both more obviously related to object identification and hence to threat detection. The fact that neither shows an effect of caffeine and that both experiments have very low power suggests that it may be worth repeating these experiments with larger samples (though not so large that a statistically significant finding represents a trivial effect) in order to determine whether there is in fact no effect of caffeine on these tasks, in which case the theory will need redefining, or whether lack of power is obscuring the situation.

In addition, no facilities for measuring physiological indicators (such as salivary cortisol, or patterns of blood flow) were available at the time data were collected. Since the notion that caffeine ingestion increases cortical arousal is well supported both theoretically and empirically in the literature, this may not be of particular significance, but, without the actual measurements, the significance or otherwise of this omission can only be a matter for conjecture.

Most of the experiments were carried out under laboratory conditions: though this strategy may have had a positive effect on reducing potential extraneous variables, it has inevitably raised questions about ecological validity. In an attempt to counter this charge, a field experiment, reported in Chapter Five, was carried out in a working police station. However, the distractions of a busy police station, for both participants and researcher, proved considerable and it was decided that potential loss of ecological validity, through return to a laboratory-based paradigm, was the least worst option.

An additional way in which this research (and almost all other research involving caffeine use) is potentially compromised is predictable from the specificity hypothesis. Since caffeine ingestion achieves its behavioural effects through increased arousal, baseline measurements of arousal are an ideally necessary prerequisite to any experiment involving caffeine. In the present research, although baseline measurements of performance were taken whenever feasible, baseline measurements of arousal were taken only once, using the SACL. This indicator has no provision for separating out trait stress/arousal from state stress/arousal, which leaves questions as to whether the findings reported here are accurate or confounded.

8.4. Implications for Further Work

The body's response to stress in general and the alarm response in particular is complex and still poorly understood. However, even at the present level of understanding, there are many more experiments which may be undertaken to test the strength of the present thesis and situations to which the present findings may be applied.

8.4.1. Caffeine's Potential Effects on Communication and Cooperation

In the author's opinion, one of the most important of the presently hypothetical, future experiments involves assessing the effect of caffeine ingestion on the social vagus. Porges argues that the higher apes, at a level of stress that is severe enough to engage the social vagus but not sufficiently high to disable higher cognitive functions, utilise additional communication through facial gestures, body language and verbal 'language' of varying complexity. On this basis, it is possible that caffeine ingestion in humans results in increased verbal fluency and greater motivation to resolve a problem cooperatively: if this were shown to be the case there are many situations encompassing conflict where such benefits would be welcomed.

Human behaviour offers many examples of caffeinated beverages being drunk in small sociable groups or as a part of greeting rituals. Anecdotally it is reported that many armed forces personnel rely heavily on their 'brew' whilst on active service and many emergency workers claim to rely on tea or coffee to get them through their shifts with a clear head. The question of interest is whether caffeine ingestion, as well as increasing endurance and allowing individuals carrying out demanding jobs to function well cognitively, also increases cooperative problem solving through, according to Polyvagal Theory, engagement of the social vagus.

Since there is presently no way of monitoring the engagement of the social vagus, this question will have to be addressed through the observation of behavioural changes, and the appropriate measurement of these changes. There is certainly anecdotal evidence of a qualitative change in behaviour of people who have shared stressful experiences together: for example, small groups who have been trapped in a lift for several hours report feeling a special kind of bond with their fellow sufferers which persists long after the emergency is past. Similarly, it was reported that during the bombing of this country during World War II, people were much friendlier and more helpful than ever before or

since. Despite the reconstructive nature of memory, there seems to be a general consensus of what might almost be called a ‘trauma bond’, in which the social vagus may play a part.

If this is the case, and with reference to the inferred engagement of the social vagus, it is possible that caffeine ingestion may shift individuals towards the higher end of a cooperation continuum. Mechanisms which elicit greater cooperation hold much potential value, both to individuals and to groups, and are argued to be very worthwhile pursuing.

An appropriate experimental protocol is not immediately obvious, since it requires a problem which affects all participants and requires face-to-face discussion. The standard measure of verbal fluency (e.g. generate names beginning with the letter P) does not seem to be appropriate, and is perhaps a better measure of memory and domain specific knowledge than verbal fluency *per se*. Formal problems such as the iterated prisoner’s dilemma (Axelrod and Wu 1995) contain the required element of cooperation necessary for successful resolution but do not involve verbal fluency. Since the potential goal of greater cooperation is deemed so desirable, there seems little doubt that additional work will uncover a suitable experimental protocol, at which point it will be of considerable interest to test whether caffeine ingestion is able to shift individuals towards talkative cooperation, in the way that a genuine communal threat appears to do.

Should it prove to be the case that caffeine ingestion does enhance social skills and ‘diplomacy’, this would constitute a third strand to the argument that caffeine use promotes adaptive behaviours, the first two strands being caffeine’s ability to improve physical speed and endurance and, as argued in this thesis, caffeine’s ability to enhance threat detection skills.

8.4.2. Caffeine’s Potential Effects on Other Cognitive and Sensory-Perceptual Processes

The present thesis opens up the possibility that there may be other areas of perceptual-cognitive processing that may also be enhanced, or impaired, by caffeine ingestion. Examples of tasks in the area of visual perception that may plausibly be predicted to show positive effects of caffeine use are tasks utilizing performance on a progressively

degraded stimulus and tasks where part, or parts, of the stimulus is occluded. In addition it will be of interest to test the effects of caffeine ingestion on contrast sensitivity function (CSF) and visual acuity. A plausible prediction would be that CSF, which enables decisions to be made as to whether something or nothing is present, through a comparison of spatial frequencies, will be susceptible to the effects of caffeine ingestion. On the other hand, visual acuity is theoretically less likely to be susceptible to caffeine ingestion, since knowing what kind of thing is near (threatening or non-threatening), rather than absolute accuracy and precision, is likely to be sufficient to improve survival chances.

Although humans rely more on vision than on any other sense, there is no reason why other senses may not be subject to caffeine's effects, in proportion to their ability to detect potential threat. The effect of caffeine ingestion on auditory stimuli is very much under-researched but, since a novel sound will give an indication of the distance, direction and possibly even the nature of a strange animal or unknown human, there is clear potential for enhanced hearing to be adaptive. Similarly, touch may be sensitive to caffeine's effects. Individuals who are stressed (regardless of the source of the stress) tend to overreact when touched unexpectedly, and careful monitoring of who is within touching distance may well promote survival. Caffeine's effects on or sense of touch appears not to have been examined experimentally.

8.4.3. Caffeine's Potential to Impair Normal Processing

The finding that caffeine use disrupts global processing is considered to be of particular importance and to offer a new direction for further research. The disruption to global processing has potentially significant applications in a number of fields, discussed below, but also points to the possibility that there may be other cognitive processes which are similarly impeded by caffeine use. Instances in which caffeine use causes performance to deteriorate are very rare in the literature but, since caffeine is used extensively on a worldwide basis, it is seen as a matter of urgency that an attempt to identify which other perceptual cognitive processes caffeine use may affect negatively, as well as positively, is undertaken.

8.4.4. Methodological Implications for Further Research

With respect to research on the effects of caffeine ingestion, one of the more important methodological notions to emerge from the present work is the necessity to take pre caffeine measures of stress/arousal, since not doing so increases the potential of any experimental results to be confounded.

Since ‘arousal’ and ‘stress’ are such problematic concepts, ideally this measure would be triangulated, for example, using the latest version of a psychometric measurement instrument, such as the Beck Anxiety Inventory (Beck, Epstein, Brown and Steer 1988) or the Spielberger Test Anxiety Inventory (Spielberger 1983), and physiological measures such as salivary cortisol and finger temperature.

After the caffeine-related experiment has been carried out the participants’ data may readily be analysed statistically into ‘high’ and ‘low’ anxiety groups (in addition to the requirements of the primary caffeine experiment), to test the hypothesis that anxiety-related interference will be evident in the high anxiety group prior to caffeine ingestion. Differing levels of anxiety/arousal due to natural diversity are readily partialled out by the use of analysis of covariance, but only when the researcher has had the foresight to take the initial baseline measurements.

In addition, the notion that caffeine is a useful model of drug dependence, raised by a number of researchers (e.g. Griffiths and Chausmer 2000), is seen to be generally untenable. Caffeine may prove to be a useful model for any other substance that elicits the mammalian stress response, but to propose it as a suitable model for nicotine, cannabis, heroin or similarly addictive substances, presently seems ill-judged.

8.5. Applications of the Present Findings

Practical applications of the theory and empirical findings appear to fall into three main categories: specific, general and theoretical.

8.5.1. Specific Applications

Potential applications for specific findings include, for example, the finding that global processing is disrupted by caffeine ingestion. Although there are undoubtedly very many real world applications where this finding is important, the fact that faces are

processed globally and subsequent potential for disruption to face recognition, seems especially demanding of further examination.

It was argued in Chapter Five that the increased arousal caused by caffeine ingestion may be having a similar effect to the increased arousal caused by being a witness to, or victim of, a crime, since in both cases the mammalian stress response is inferred to be engaged. It would be useful to test this hypothesis because in such cases, despite protestations, such as 'I will never forget his eyes/face', witnesses and victims frequently fail to establish good likenesses of the perpetrator, although it would clearly be of help to the police and other potential victims to do so.

One way of tackling this problem, based on the theory of state dependent memory, would be to recreate stress/arousal in witnesses, as was suggested in Chapter Five, either through caffeine ingestion or some other ethically acceptable method. Alternatively, Gibson, a forensic artist working in the Houston police department, whose work in helping to identify over a thousand individuals of interest to the police has earned her a place in the book of Guinness World Records (Folkard 2006), argues the reverse, that only when witnesses are induced into a very relaxed state are they able to remember information useful for identification (Gibson 2008). In terms of the specificity hypothesis and Polyvagal Theory, the increased arousal caused by both caffeine and by being the victim of crime, temporarily removes access to higher cognitive processing, including global processing and, theoretically, restoring relaxed awareness has the potential to restore such access. An experiment to test the efficacy of these two competing procedures for the restoration of global processing in the context of face recognition would, in the author's opinion, be very worthwhile.

8.5.2. General Applications

There are likely to be very many other everyday applications where caffeine's effects on global processing, categorisation, field dependence-independence, aspects of visuo-spatial ability and venturesomeness are relevant. Since enhancement or disruption of the cognitive processes underlying these tasks may have serious consequences in the world outside the laboratory, it is suggested that this offers a rich seam of potential research waiting to be mined.

A study of the literature on caffeine's effects reveals an interesting pattern: in earlier caffeine research, particularly in the 1970s and 1980s whole or gross behaviours were studied, particularly in relation to cognition and perception. However, as methods able to record living brain activity became available such experiments fell out of favour. This may be because the earlier experiments appeared to be contradictory, only some aspect of a behaviour being affected, or it may be that studies of brain activity were hoped to be more revealing of underlying processes than has so far proved to be the case. In the author's opinion there is a need for both kinds of experiments and it is hoped that the recent experiments, such as that showing that the equivalent of five cups of coffee a day not only precludes the development of Alzheimer's disease in mice but actually reverses it, (Arendash, Mori, Cao, Mamcarz, Runfeldt, Dickson, Rezai-Zadeh, Tan, Citron, Lin, Echverria and Potter 2009), and other work focussing on caffeine's effects on behaviour, such as the specificity hypothesis, will encourage more studies of caffeine's effects on gross behaviours as well as on brain function.

8.5.3. Theoretical Applications

The findings of the current research project have raised questions about the nature of constructs which underlie established cognitive concepts. For example, the notion that field dependence may be considered a relatively fixed personality trait is not supported by the current findings. Indeed, to obtain accurate information on an individual's position on the field dependence-independence continuum, it is suggested that a trait/state approach is taken, together with measures of stress-arousal. Since the GEFT and PEFT appear to be tapping different processes, figure-ground discrimination may be better described as a perceptual skill than an aspect of intelligence or personality. Similarly, notions of mental input and output processes, commonly used in the study of psychology, may be too general to be useful in real world applications, whilst retaining their usefulness in terms of cognitive modelling.

8.6. Wider Implications

The degree to which some aspects of cognitive processing, including the somewhat esoteric aspects of visuo-spatial processing, such as the generation of three dimensional shapes, integration and rotation of mental images, have been shown to improve upon a single instance of practice is also of interest. It may be that such phenomena could usefully be considered skills, rather than differing levels of innate ability, in which case

training, in or out of school, might go some way towards filling the skills gap we are apparently experiencing in this country.

With respect to caffeine's documented negative effects on fecundity, it would be of interest to discover how many women give up caffeine when they are pregnant. Today the medical profession generally advises this course of action but there are anecdotal reports of women who, though previously regular coffee drinkers, were unable to tolerate either the smell or taste of coffee as soon as they became pregnant. It is well known in conservation work that animals will not breed when stressed, so it may be that such women have some kind of awareness of the fact that caffeine ingestion results in the body responding as though to threat.

Perhaps most importantly, the present thesis suggests the possibility that caffeine ingestion may provide a useful model of stress/arousal, or anxiety, in some circumstances. It is generally accepted that individuals perform less well on a range of tasks when they are anxious. If, as seems plausible, anxiety is the subjective experience of unconscious threat detection, then it is possible that a similar pattern of performance deficits is elicited by anxiety as is elicited by caffeine ingestion. If this were found to be the case, the implications would be substantial, given the prevalence of both low level anxiety and anxiety disorders in modern society. It would also point to the possibility that a substance that blocks adenosine receptors may offer relief to anxious individuals. Anxiety-prone individuals may have more adenosine receptors than non-anxious individuals, in which case partial blocking may relieve excessive anxiety although, of course, total blocking might well leave an individual susceptible to social and environmental threats sufficiently severe to require attention.

However, a number of problems with data collection have been considered during this thesis. One of the more important of these may be that the experimenter relied on the honesty of the participants as to when they had last ingested caffeine, prior to the experiment. This is unsatisfactory, but with the equipment available to the experimenter was unavoidable. In addition, sample size was sometimes small and in some cases collection of more details (for example, type and strength of religious belief) from participants would give more confidence as to lack of confounding variables. On the other hand, experiments were carried out double-blind, allocation to condition was

always random and widely tested measurement instruments were used. It would be useful if the work could be replicated under more ideal circumstances in order to clarify the present findings.

8.7. Final Conclusions

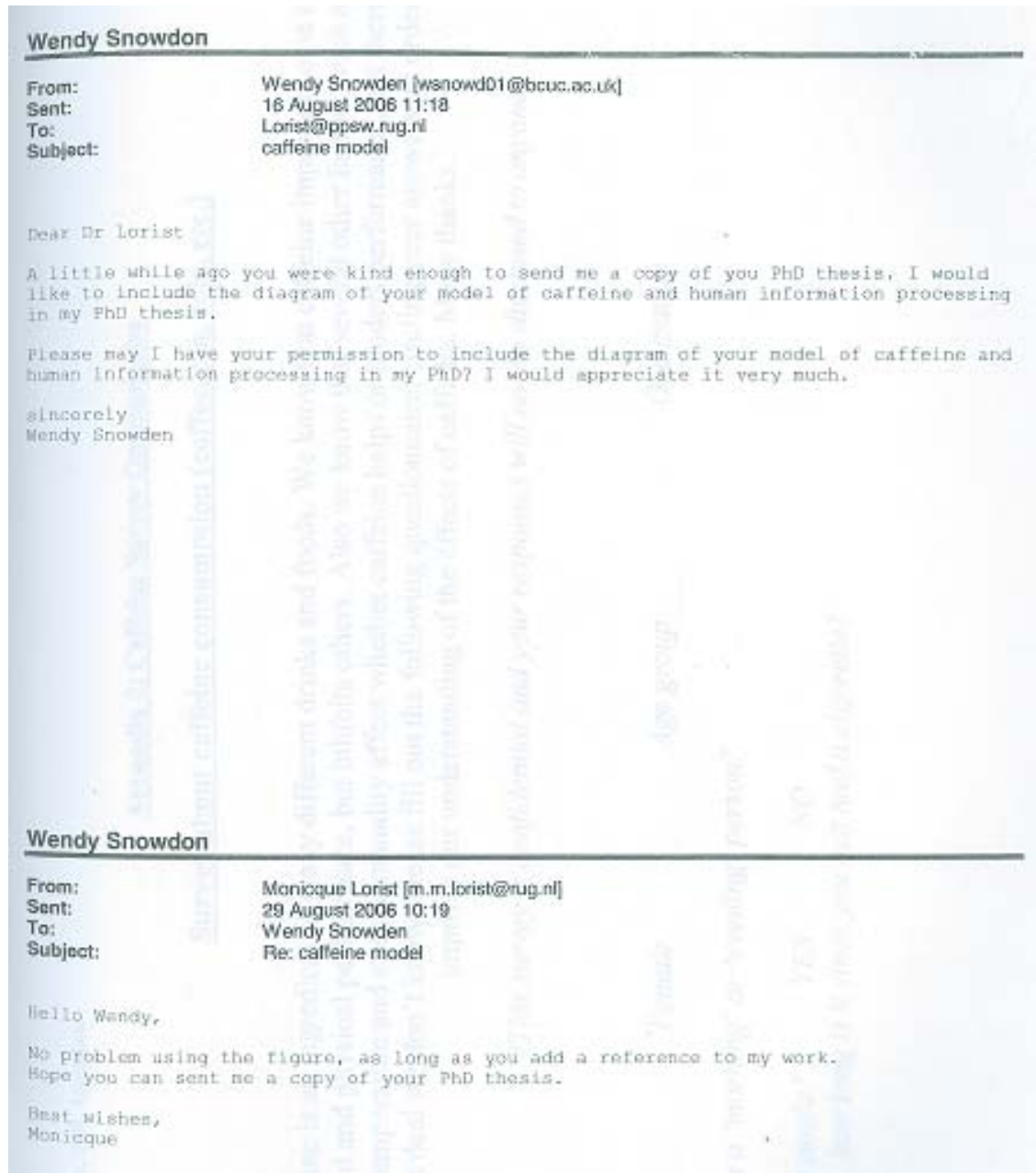
All the above potential implications depend on the strength of the specificity hypothesis, which itself depends on replication by others of the present findings. If, as is hoped, further empirical studies are carried out to test and extend the thesis that caffeine's effects are specific to threat-related processes, and hence moderate caffeine use is promotes adaptive behaviour, it is very likely that over time accommodations will have to be made to the theory. However, the argument is firmly grounded in Polyvagal Theory, which is bulwarked by extensive and detailed thinking and by the substantial body of both theoretical and empirical papers published by Porges. Future adjustments to the theory put forward here may well prove necessary but it is argued that the general principle that caffeine's effects are specific and that moderate caffeine promotes adaptive behaviours are likely to survive, even as the general theory evolves. It is hoped that the specificity hypothesis may provide a starting point for further research on caffeine-related issues, in much the same way that Lorist's model inspired the present thesis.

It is concluded both from the literature and from the experiments reported here that caffeine ingestion will sometimes reduce error rate and sometimes increase it, sometimes reduce response time and sometimes increase it and sometimes make no difference. These effects, however, are not arbitrary but rather are elicited by the nature of the tasks (for example, on visual vigilance tasks caffeine ingestion improves performance whereas on global processing tasks caffeine ingestion degrades performance). Given the widespread use of caffeine, it is seen as a point of considerable interest that further research, to establish more fully the effects of caffeine ingestion on particular kinds of processes and behaviours, is carried out. The present thesis argues that whilst degrading global processes, such as face recognition, caffeine ingestion improves processes underlying threat detection, such as figure-ground separation and object identification, to name two of many such processes, together with behaviours which offer greater potential for successful flight when faced with danger. No doubt

further experiments will enable the pattern of caffeine's effects to be seen more clearly, but it is argued strongly here that that pattern is unlikely to be arbitrary.

Appendix i

Permission from Lorist to use her Cognitive Model



Appendix ii

Caffeine Survey Questionnaire

Survey about caffeine consumption (coffee, tea, cola, etc.)

Caffeine is an ingredient of many different drinks and foods. We know that caffeine improves some aspects of mental and physical performance, but inhibits others. Also we know that several other factors, such as time of day, temperature and even personality affect whether caffeine helps or hinders performance, but there is still a great deal we don't know. Please fill out the following questionnaire, circling your answers, in order to help improve our understanding of the effects of caffeine. Many thanks.

(This survey is confidential and your responses will not be disclosed to anyone)

Male

Female

Age group

Occupation

Are you a 'morning' or 'evening' person?

Do you smoke?

YES

NO

If 'yes', how long is it since you last had a cigarette?

(1) How many cups/mugs of coffee do you usually drink in a 24 hour period?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(2) How long, in hours, is it since you last drank coffee?	
(3) On what day/s of the week do you consume most coffee?	Mon, Tues, Wed, Thu, Fri, Sat, Sun
(4) At what time of day do you drink most coffee?	Morning, afternoon, evening, night
(5) How many cans of <u>cola</u> do you usually drink in a 24 hour period?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(6) How long, in hours, is it since you last drank cola?	
(7) On what day/s of the week do you drink most cola?	Mon, Tues, Wed, Thu, Fri, Sat, Sun
(8) At what time of day do you drink most cola?	Morning, afternoon, evening, night
(9) How many cups/mugs of <u>tea</u> do you usually drink in a 24 hour period?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(10) How long, in hours, is it since you last drank tea?	
(11) On what day/s of the week do you drink most tea?	Mon, Tue, Wed, Thu, Fri, Sat, Sun
(12) At what time of the day do you drink most tea?	Morning, afternoon, evening, night
(13) How many cans of <u>Red Bull</u> (or similar) do you usually drink in a week?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(14) How often do you drink <u>Red Bull with alcohol</u> in a week?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(15) How long, in hours, is it since you last drank Red Bull (or similar)?	
(16) On what day/s of the week do you drink most Red Bull (or similar)?	Mon, Tues, Wed, Thu, Fri, Sat, Sun
(17) At what time of the day do you drink most Red Bull (or similar)?	Morning, afternoon, evening, night
(18) How many <u>chocolate</u> bars do you eat in a week?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(19) How long, in hours, is it since you last ate a chocolate bar?	
(20) On what day/s of the week do you eat most chocolate?	Mon, Tue, Wed, Thu, Fri, Sat, Sun
(21) At what time of day do you eat most chocolate?	Morning, afternoon, evening, night
(22) How many <u>tablets of caffeine</u> do you take in a week?	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+
(23) How long, in hours, is it since you last took caffeine tablets?	
(24) On what day/s of the week do you consume most caffeine tablets?	Mon, Tues, Wed, Thu, Fri, Sat, Sun
(25) At what time of day do you consume most caffeine tablets?	Morning, afternoon, evening, night

Appendix iii

Impulsiveness, Venturesomeness and Empathy Questionnaire

Please answer the following questions by putting a circle round the number which applies to your situation. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the questions.

(Your responses are anonymous and confidential)

	Very much.	A little.	Unsure.	Not much.	Not at all.
	1	2	3	4	5
1 Would you enjoy water ski-ing?	1	2	3	4	5
2 Usually do you prefer to stick to brands you know are reliable, to trying new ones on the chance of finding something better?	1	2	3	4	5
3 Would you feel sorry for a lonely stranger?	1	2	3	4	5
4 Do you quite enjoy taking risks?	1	2	3	4	5
5 Do you often get involved with your friends' problems?	1	2	3	4	5
6 Would you enjoy parachute jumping?	1	2	3	4	5
7 Do you often buy things on impulse?	1	2	3	4	5
8 Do unhappy people who feel sorry for themselves irritate you?	1	2	3	4	5
9 Do you generally do and say things without stopping to think?	1	2	3	4	5
10 Are you inclined to get nervous when others around you seem to be nervous?	1	2	3	4	5
11 Do you often get into a jam because you do things without thinking?	1	2	3	4	5
12 Do you think hitch-hiking is a dangerous way to travel?	1	2	3	4	5
13 Do you find it silly for people to cry out of happiness?	1	2	3	4	5
14 Do you like diving off the high-board?	1	2	3	4	5
15 Do people you are with have a strong influence on your moods?	1	2	3	4	5
16 Are you an impulsive person?	1	2	3	4	5
17 Do you welcome new and exciting experiences and sensations, even if they are a little frightening and unconventional?	1	2	3	4	5
18 Does it affect you very much when one of your friends seems upset?	1	2	3	4	5
19 Do you usually think carefully before doing anything?	1	2	3	4	5
20 Would you like to learn to fly an aeroplane?	1	2	3	4	5
21 Do you ever get deeply involved with the feelings of a character in a film, play or novel?	1	2	3	4	5
22 Do you often do things on the spur of the moment?	1	2	3	4	5
23 Do you get very upset when you see someone cry?	1	2	3	4	5
24 Do you sometimes find someone else's laughter catching?	1	2	3	4	5
25 Do you mostly speak without thinking things out?	1	2	3	4	5
26 Do you often get involved in things you later wish you could get out of?	1	2	3	4	5

	Very much	A little	Unsure	Not much	Not at all
27 Do you get so 'carried away' by new and exciting ideas, that you never think of possible snags?	1	2	3	4	5
28 Do you find it hard to understand people who risk their necks climbing?	1	2	3	4	5
29 Can you make decisions without worrying about other people's feelings?	1	2	3	4	5
30 Do you sometimes like doing things that are a bit frightening?	1	2	3	4	5
31 Do you need to use a lot of self-control to keep out of trouble?	1	2	3	4	5
32 Do you become more irritated than sympathetic when you see someone cry?	1	2	3	4	5
33 Would you agree that almost everything enjoyable is illegal or immoral?	1	2	3	4	5
34 Generally do you prefer to enter cold sea water gradually, to diving or jumping straight in?	1	2	3	4	5
35 Are you often surprised at people's reactions to what you do or say?	1	2	3	4	5
36 Would you enjoy the sensation of skiing very fast down a high mountain slope?	1	2	3	4	5
37 Do you like watching people open presents?	1	2	3	4	5
38 Do you think an evening out is more successful if it is unplanned or arranged at the last moment?	1	2	3	4	5
39 Would you like to go scuba diving?	1	2	3	4	5
40 Would you find it very hard to beak bad news to someone?	1	2	3	4	5
41 Would you enjoy fast driving?	1	2	3	4	5
42 Do you usually work quickly, without bothering to check?	1	2	3	4	5
43 Do you often change your interests?	1	2	3	4	5
44 Before making up your mind, do you consider all the advantages and disadvantages?	1	2	3	4	5
45 Can you get very interested in your friends' problems?	1	2	3	4	5
46 Would you like to go pot-holing?	1	2	3	4	5
47 Would you be put off a job involving quite a bit of danger?	1	2	3	4	5
48 Do you prefer to 'sleep on it' before making decisions?	1	2	3	4	5
49 When people shout at you, do you usually shout back?	1	2	3	4	5]
50 Do you feel sorry for very shy people?	1	2	3	4	5
51 Are you happy when you are with a cheerful group and sad when others glum?	1	2	3	4	5
52 Do you usually make up your mind quickly?	1	2	3	4	5
53 Can you imagine what it must be like to be very lonely?	1	2	3	4	5
54 Does it worry you when others are worrying and panicky?	1	2	3	4	5

PLEASE CHECK YOU HAVE ANSWERED ALL THE QUESTIONS

Appendix iv

Verbal Processing Task

This is a test to see how quickly and accurately you can work.

You are given three words and your task is to decide which of the three comes first in alphabetical order and fill in the appropriate bubble on the separate answer sheet provided. Do not mark the test booklet.

Below are four examples. The first two have been answered for you. Try the remaining examples yourself, marking your answers in the examples section of the answer sheet.

- | | | | | | | |
|----|----------|----------|------------|-------------------------|------------------------------------|-------------------------|
| 1. | a Jones | b Jason | c Joseph | a <input type="radio"/> | b <input checked="" type="radio"/> | c <input type="radio"/> |
| 2. | a Taylor | b Tailor | c Townsend | a <input type="radio"/> | b <input checked="" type="radio"/> | c <input type="radio"/> |
| 3. | a dead | b dread | c darda | | | |
| 4. | a wisp | b willow | c wilter | | | |

The correct answer to question 3 is (c) and to 4 is (b).

In this test it is important to work as quickly as you can, but you must also make sure you work accurately.

PLEASE ASK NOW IF YOU HAVE ANY QUESTIONS OR DO NOT UNDERSTAND WHY THESE ANSWERS ARE CORRECT.

When you are given the signal to start you will have 3 minutes for this test. Remember to work as quickly and accurately as you can. You should mark your answers on the separate answer sheet provided by completely filling in the bubble alongside the answer you think is correct. If you are not sure of an answer, leave all the bubbles blank as incorrect answers will count against you.

PLEASE DO NOT TURN OVER UNTIL YOU ARE GIVEN THE SIGNAL TO START.

1	a able	b abel	c abbel
2	a tango	b tanker	c tabber
3	a swift	b switch	c stuck
4	a dean	b deal	c drift
5	a frant	b french	c freak
6	a tranter	b truck	c tramper
7	a grant	b gant	c great
8	a willis	b Wiltshire	c wilter
9	a Simons	b Simkins	c Simmons
10	a Stanley	b sturdy	c Straemar
11	a Foster	b Forster	c Fortnum
12	a Yarrow	b Yaught	c yammer
13	a pear	b Pearce	c Pearson
14	a burch	b birch	c brunch
15	a fox	b fotse	c foray
16	a Hamilton	b Harding	c hammer
17	a Gough	b Guntler	c Goff
18	a peer	b peirs	c pedlar
19	a Brown	b Browne	c Brownne
20	a Milton	b Miller	c Milstone
21	a Delafield	b Deldorfield	c Delderfield
22	a Johnson	b Johnstone	c Johnston
23	a Jackron	b Jackson	c Jackman
24	a Phillip	b Philips	c Phillippes
25	a crow	b crout	c crove

26	a Mackie	b Mackensie	c Macky
27	a young	b younger	c youngest
28	a Crispin	b Crist	c Crump
29	a Wober	b Waller	c Walters
30	a Katz	b Katin	c Kaarl
31	a Davis	b Davies	c Davit
32	a Mordecai	b Morden	c Mortimer
33	a Butler	b Buwer	c Butcher
34	a Stratford	b Stafford	c Strafford
35	a Wallis	b Wallace	c Warris
36	a Pearson	b Pearston	c Pearstron
37	a Rhostra	b Rodda	c Rhonda
38	a Tailor	b Taylor	c Tail
39	a Carter	b Carver	c Carstair
40	a Zuiler	b Zweger	c Zweeter
41	a swell	b svelte	c swallow
42	a thorough	b thought	c though
43	a dollop	b doleful	c dollard
44	a kinship	b kingship	c kindred
45	a grove	b grave	c grieve
46	a field	b flicker	c fickle
47	a portrait	b potter	c portrayed
48	a junior	b juniper	c jumper
49	a queue	b quintuplets	c quintessential
50	a bovine	b bought	c bowling

END OF TEST

Appendix v

Numerical Processing Task

63 ~~22~~ 55 92 69

83 47 ~~25~~ 45 31

25 82 ~~22~~ 24 ~~27~~

85 ~~10~~ 57 74 80

61 59 63 ~~52~~ 98

~~11~~ 27 75 20 30

90 65 86 ~~48~~ 70

21 72 73 ~~14~~ 26

47 ~~18~~ 88 71 23

44 54 ~~28~~ 48 96

~~23~~ 66 45 55 85

63 42 79 91 ~~22~~

95	18	28	64	37	305	186	869	957	544
38	44	56	89	57	882	321	569	934	405
68	70	81	54	10	324	949	618	933	799
60	90	58	87	84	684	283	419	352	528
46	31	35	82	53	733	959	563	497	719
55	12	60	47	63	651	344	783	973	886

36	24	72	38	54	80	92	26	49	94
60	81	99	12	18	50	41	21	66	27
58	69	47	83	25	39	13	50	52	13
552	784	147	158	947	70	28	29	62	31
648	224	174	325	333	64	61	55	16	31
126	265	934	990	877	58	79	39	78	81

Appendix vi

Picture Embedded Figures Test



Figure 12.2

An Embedded Figures Test, in which the objective is to find as many of the smaller figures hidden in the larger figure as possible.



Appendix vii

Group Embedded Figures Test



By Philip K. Oltman, Evelyn Raskin, & Herman A. Witkin

Name _____ Sex _____

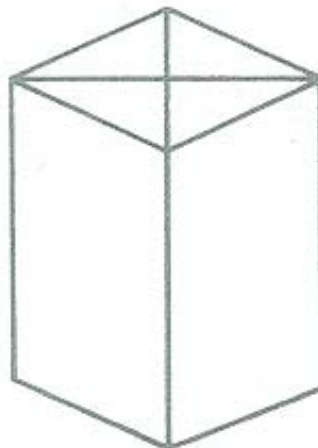
Today's date _____ Birth date _____

INSTRUCTIONS: This is a test of your ability to find a simple form when it is hidden within a complex pattern.

Here is a simple form which we have labeled "X":



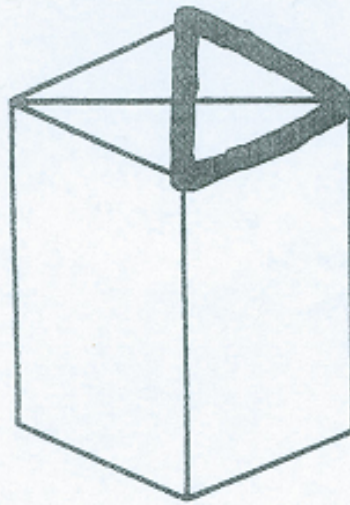
This simple form, named "X", is hidden within the more complex figure below:



Try to find the simple form in the complex figure and trace it *in pencil* directly over the lines of the complex figure. It is the SAME SIZE, in the SAME PROPORTIONS, and FACES IN THE SAME DIRECTION within the complex figure as when it appeared alone.

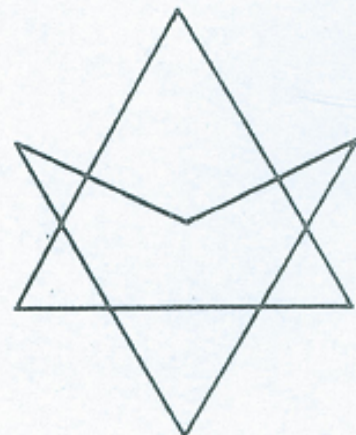
When you finish, turn the page to check your solution.

This is the correct solution, with the simple form traced over the lines of the complex figure:



Note that the top right-hand triangle is the correct one; the top left-hand triangle is similar, but faces in the opposite direction and is therefore *not* correct.

Now try another practice problem. Find and trace the simple form named "Y" in the complex figure below it:



Look at the next page to check your solution.

Solution:



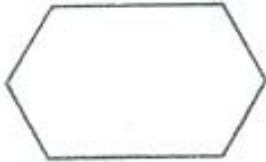
In the following pages, problems like the ones above will appear. On each page you will see a complex figure, and under it will be a letter corresponding to the simple form which is hidden in it. For each problem, look at the **BACK COVER** of this booklet to see which simple form to find. Then try to trace it in pencil over the lines of the complex figure. Note these points:

1. Look back at the simple forms as often as necessary.
2. ERASE ALL MISTAKES.
3. Do the problems in order. Don't skip a problem unless you are absolutely "stuck" on it.
4. Trace **ONLY ONE SIMPLE FORM IN EACH PROBLEM**. You may see more than one, but just trace *one* of them.
5. The simple form is always present in the complex figure in the **SAME SIZE**, the **SAME PROPORTIONS**, and **FACING IN THE SAME DIRECTION** as it appears on the back cover of this booklet.

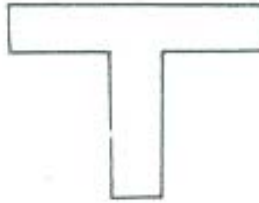
Do not turn the page until the signal is given

SIMPLE FORMS

A



B



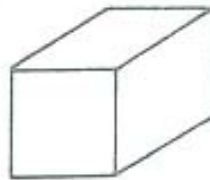
C



D



E



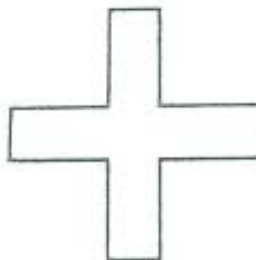
F



G

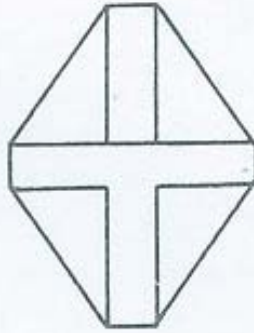


H



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1



Find Simple Form "B"

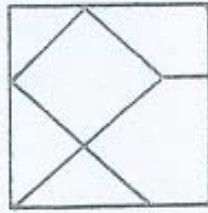
2



Find Simple Form "G"

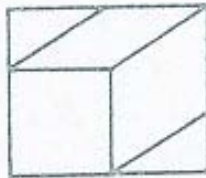
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3



Find Simple Form "D"

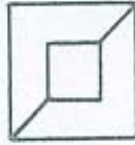
4



Find Simple Form "E"

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5



Find Simple Form "C"

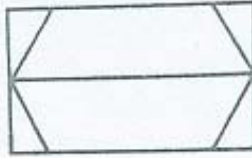
6



Find Simple Form "F"

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7



Find Simple Form "A"



**PLEASE STOP. Wait for
further instructions.**

Appendix viii

Stress Arousal Check List

SACL

The words shown below describe different feelings and moods. Please use this list to describe your feelings *at this moment*.

If the word *definitely* describes your feelings, circle the double plus (++)
 If the word *more or less* describes your feelings circle the plus (+)
 If you do not understand the word, or *you cannot decide* whether or not it describes how you feel, circle the question mark (?). If the word *does not describe* the way you feel, circle the minus (-).

First reactions are most reliable; therefore do not spend too long thinking about each word. Please be as honest and accurate as possible.

1. Tense	++	+	?	-	16. Tired	++	+	?	-
2. Relaxed	++	+	?	-	17. Idle	++	+	?	-
3. Restful	++	+	?	-	18. Up-tight	++	+	?	-
4. Active	++	+	?	-	19. Alert	++	+	?	-
5. Apprehensive	++	+	?	-	20. Lively	++	+	?	-
6. Worried	++	+	?	-	21. Cheerful	++	+	?	-
7. Energetic	++	+	?	-	22. Contented	++	+	?	-
8. Drowsy	++	+	?	-	23. Jittery	++	+	?	-
9. Bothered	++	+	?	-	24. Sluggish	++	+	?	-
10. Uneasy	++	+	?	-	25. Pleasant	++	+	?	-
11. Dejected	++	+	?	-	26. Sleepy	++	+	?	-
12. Nervous	++	+	?	-	27. Comfortable	++	+	?	-
13. Distressed	++	+	?	-	28. Calm	++	+	?	-
14. Vigorous	++	+	?	-	29. Stimulated	++	+	?	-
15. Peaceful	++	+	?	-	30. Activated	++	+	?	-

Appendix ix

Phobic Stroop

SNAKE
SPIDER
RAT
MOUSE
INSECT
BIRDS
WORM
BLOOD
CROWD
GERM
NEEDLE
KNIFE
SNAKE
SPIDER
RAT
MOUSE
INSECT
BIRDS
WORM
BLOOD
CROWD
GERM
NEEDLE
KNIFE
SNAKE
SPIDER
RAT
MOUSE
INSECT
BIRDS
WORM
BLOOD
CROWD
GERM
NEEDLE
KNIFE
SNAKE
SPIDER
RAT
MOUSE
INSECT
BIRDS
WORM
BLOOD
CROWD
GERM
NEEDLE
KNIFE

BUNCH
NATION
GYM
COUCH
GUITAR
CAKES
WALL
EARTH
BREAD
DUCK
MUSCLE
CHAIN
BUNCH
NATION
GYM
COUCH
GUITAR
CAKES
WALL
EARTH
BREAD
DUCK
MUSCLE
CHAIN
BUNCH
NATION
GYM
COUCH
GUITAR
CAKES
WALL
EARTH
BREAD
DUCK
MUSCLE
CHAIN
BUNCH
NATION
GYM
COUCH
GUITAR
CAKES
WALL
EARTH
BREAD
DUCK
MUSCLE
CHAIN

Appendix x

Pylyshyn's Stimulus Figures

Stimulus Figure	Probe A	Probe B	Probe C	Probe D

Appendix xi

General Ability Test 2, Spatial Test

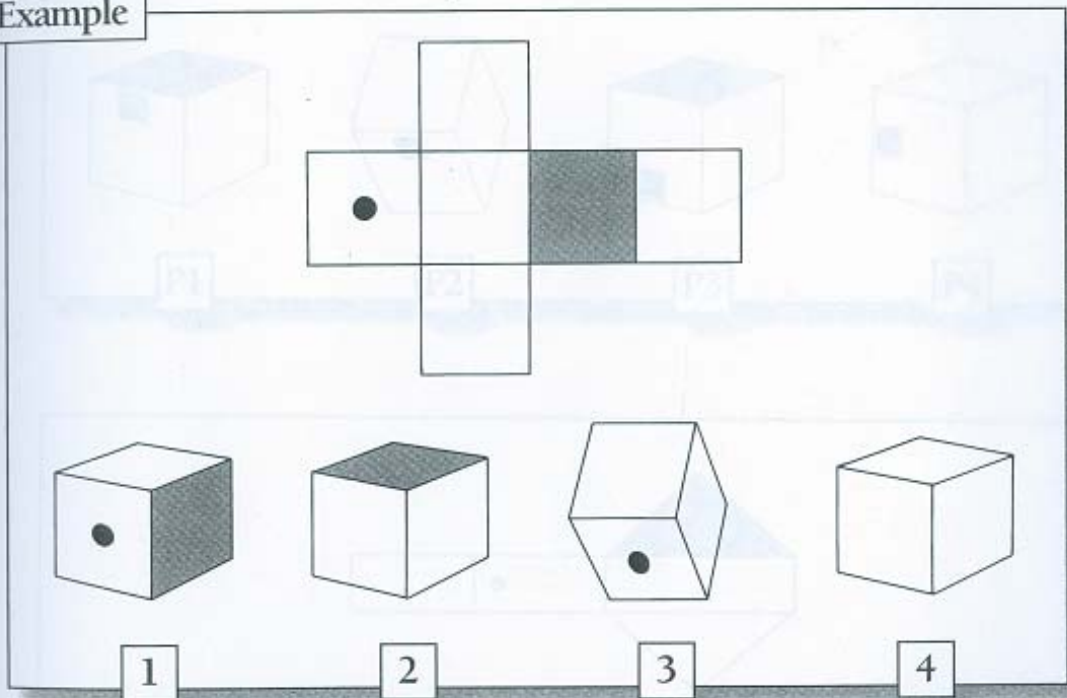
Spatial Instructions

In this test you have to imagine what a flat pattern would look like if it were cut out and folded into a solid object. The patterns have to be folded along the black lines, so that the markings are on the **outside** of the solid object.

You have to decide if each of the solid objects shown below the flat pattern could be made from it when folded. Answer **no** if an object definitely could not be made, and **yes** if it definitely could be made. If you cannot be sure without seeing the hidden sides, answer **yes**.

Look at this example:

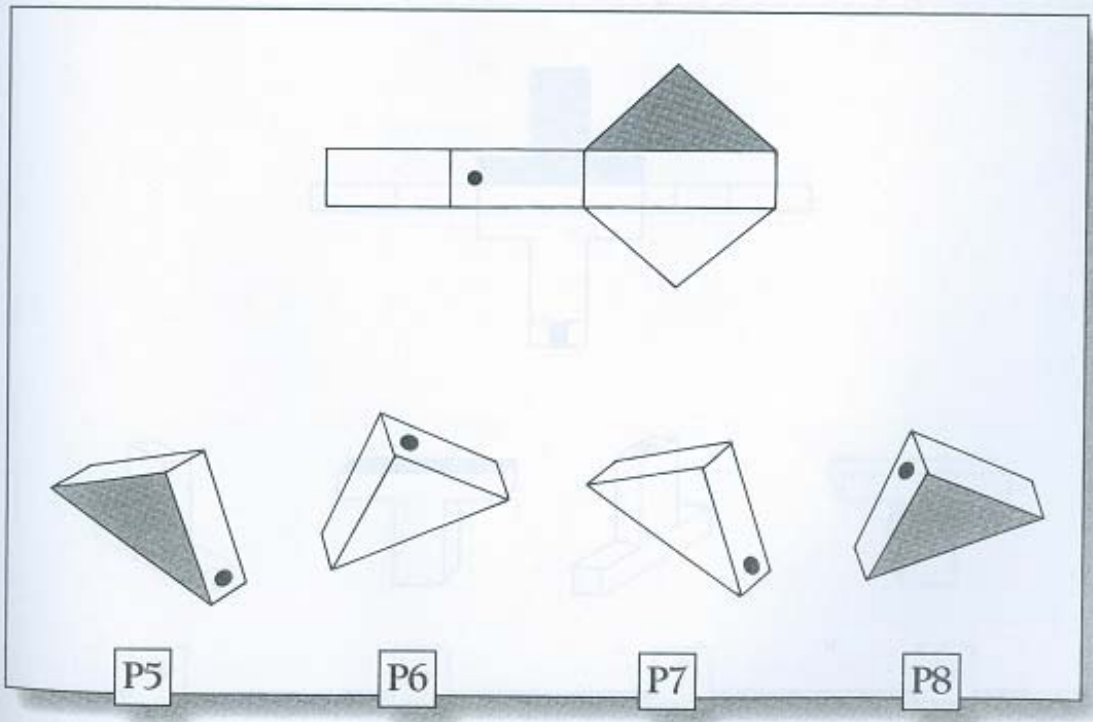
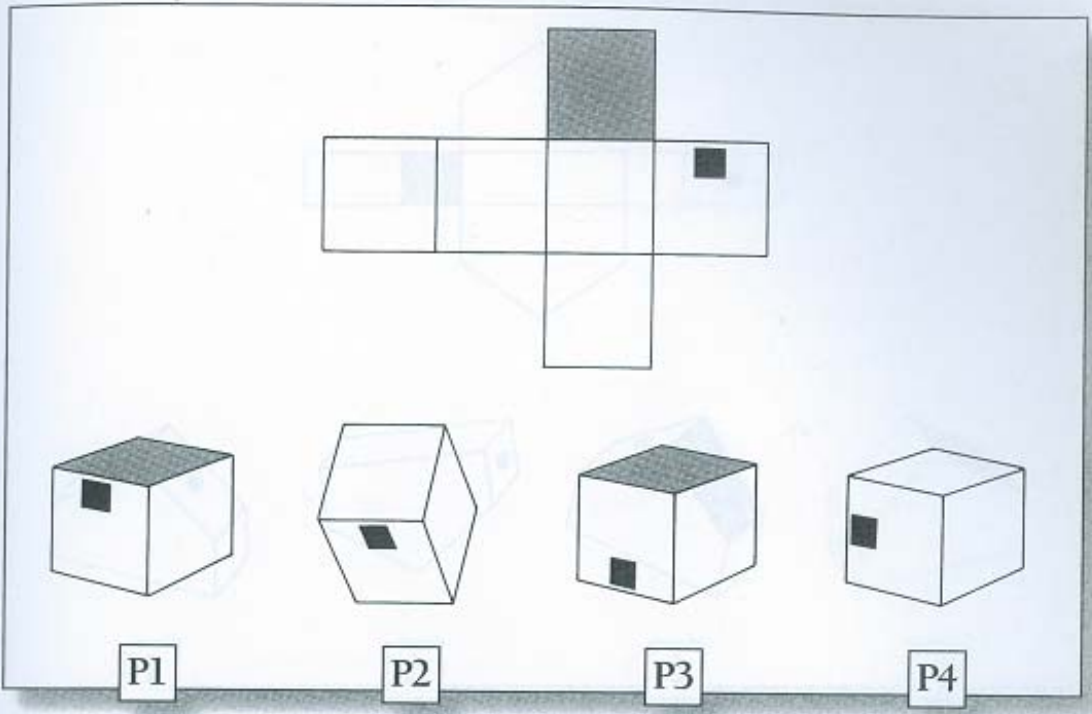
Example



If the pattern were folded up it would form a cube with the black face and the dot on opposite sides. The answer to Question 1 is **no**, since it shows a cube with the dot and black face next to each other. Question 2 might be made from the pattern, since the dot could be on the hidden side under the cube, so the answer is **yes**. Likewise, Question 3 might be made from the pattern if the black face is hidden at the top of the cube, so the answer is **yes**. In Question 4, each of the three hidden sides has its opposite side in view so either the dot or the black face would have to be visible. Therefore, it definitely cannot be made from the pattern, so the answer is **no**.

Now turn over and do the practice questions (four to each pattern). Mark your answers in the Spatial Test practice section on your answer sheet. **After doing the practice test, do not turn over until told to do so.**

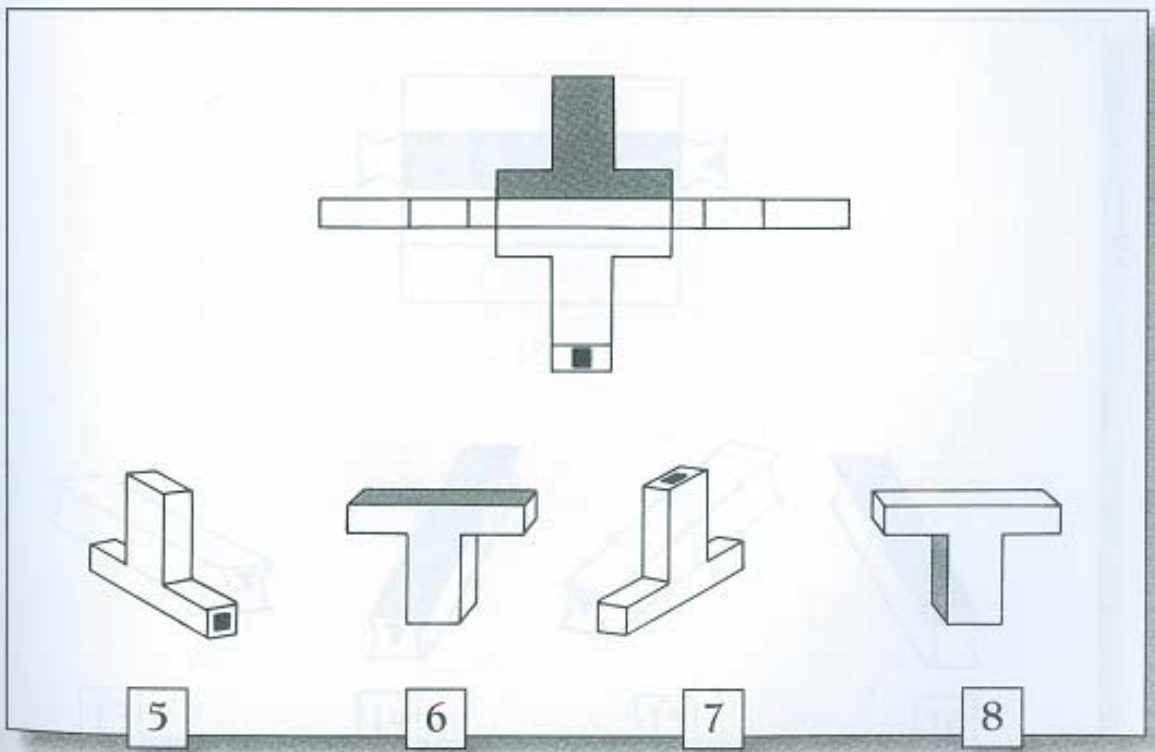
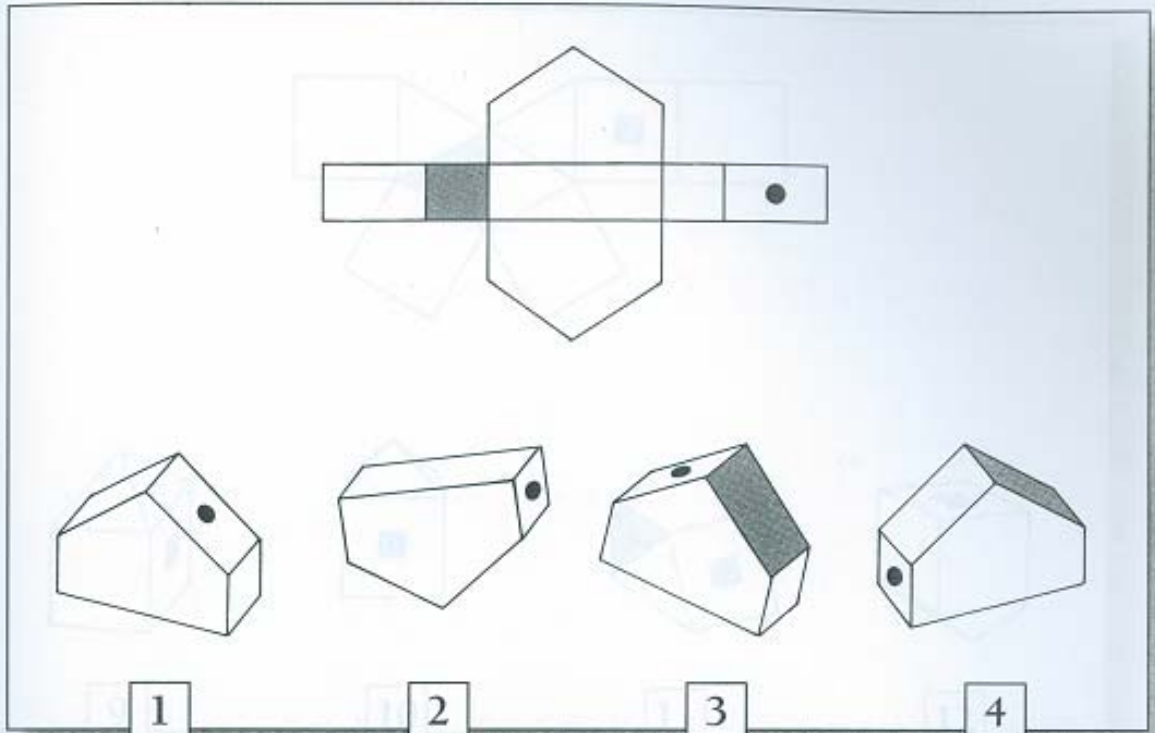
PRACTICE TEST



Do not turn over

Make no marks on this page

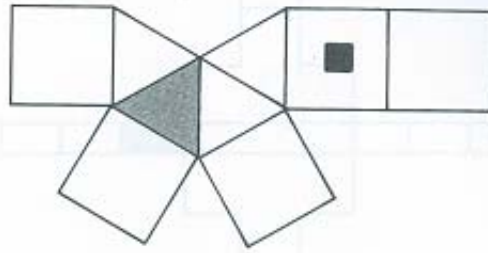
MAIN TEST



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Make no marks on this page

Make no marks on this page



9



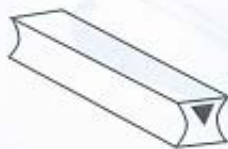
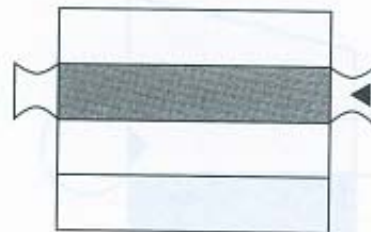
10



11



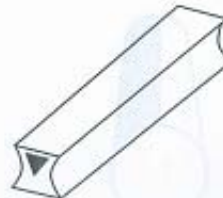
12



13



14



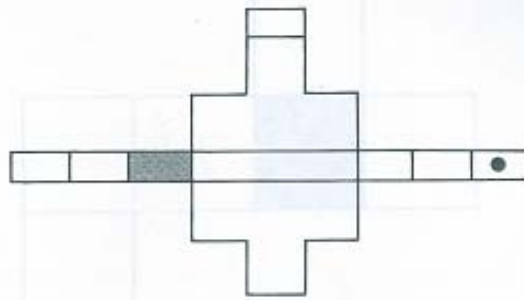
15



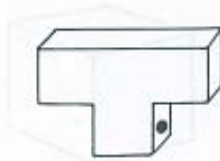
16

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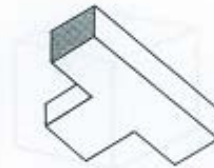
Make no marks on this page



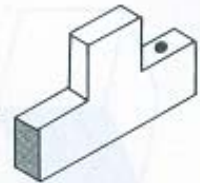
17



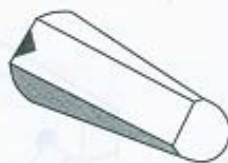
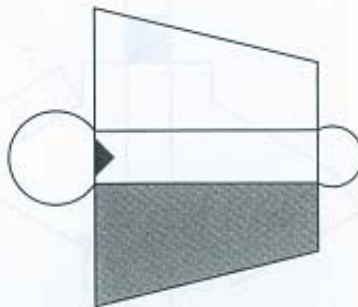
18



19



20



21



22



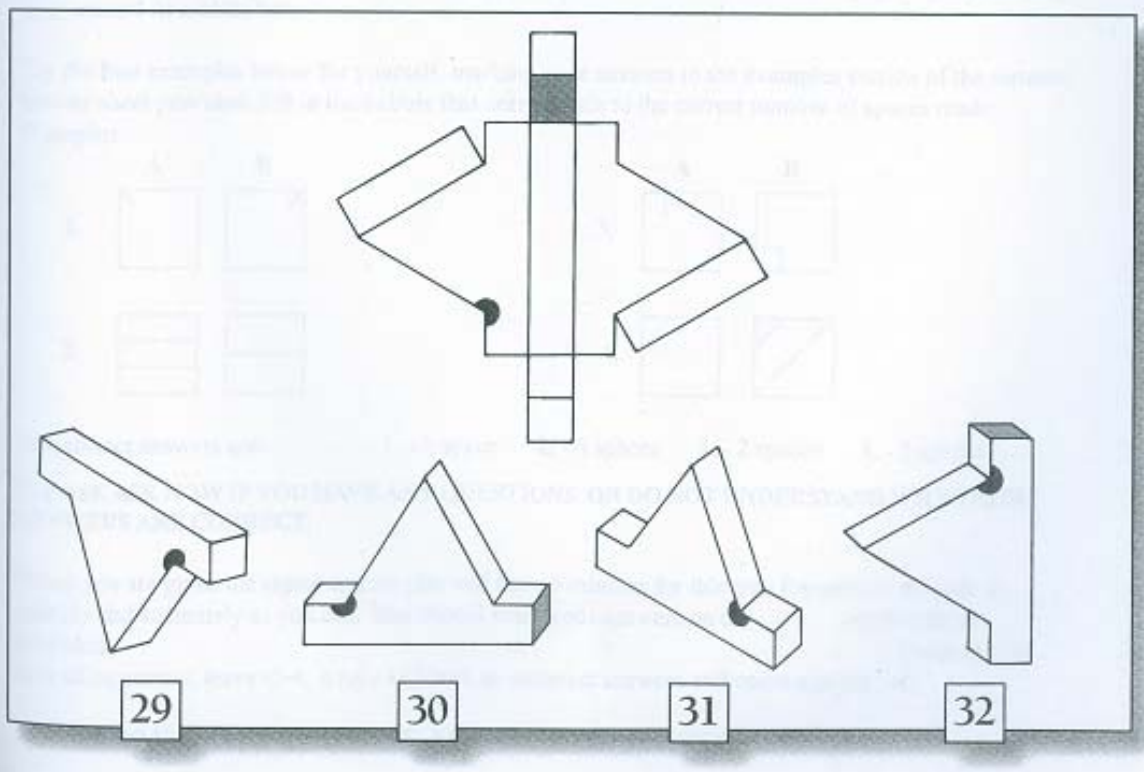
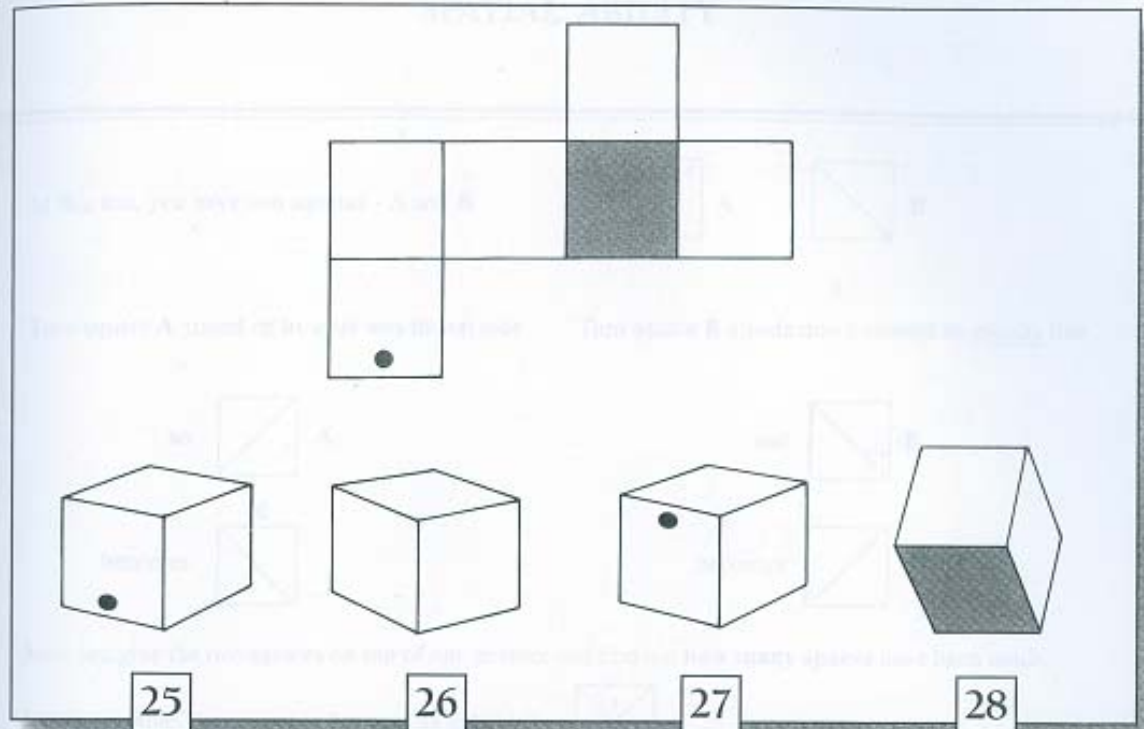
23



24

Go on to the next page

Make no marks on this page




Appendix xii


Power and Performance Measures Test of Spatial Ability

SPATIAL ABILITY

In this test, you have two squares - A and B




A



B


Turn square A round on to what was its left side Turn square B upside down around its middle line.

so




A

becomes




and



B


becomes



B

Now imagine the two squares on top of one another and find out **how many** spaces have been made.

In our example, the answer is 4 spaces as indicated





Remember, square A is always turned through 90 degrees anticlockwise and square B is always turned over around its middle line.



Try the four examples below for yourself, marking your answers in the examples section of the separate answer sheet provided. Fill in the bubble that corresponds to the correct number of spaces made.



Examples



A B

1.  

A B

3.  

2.  

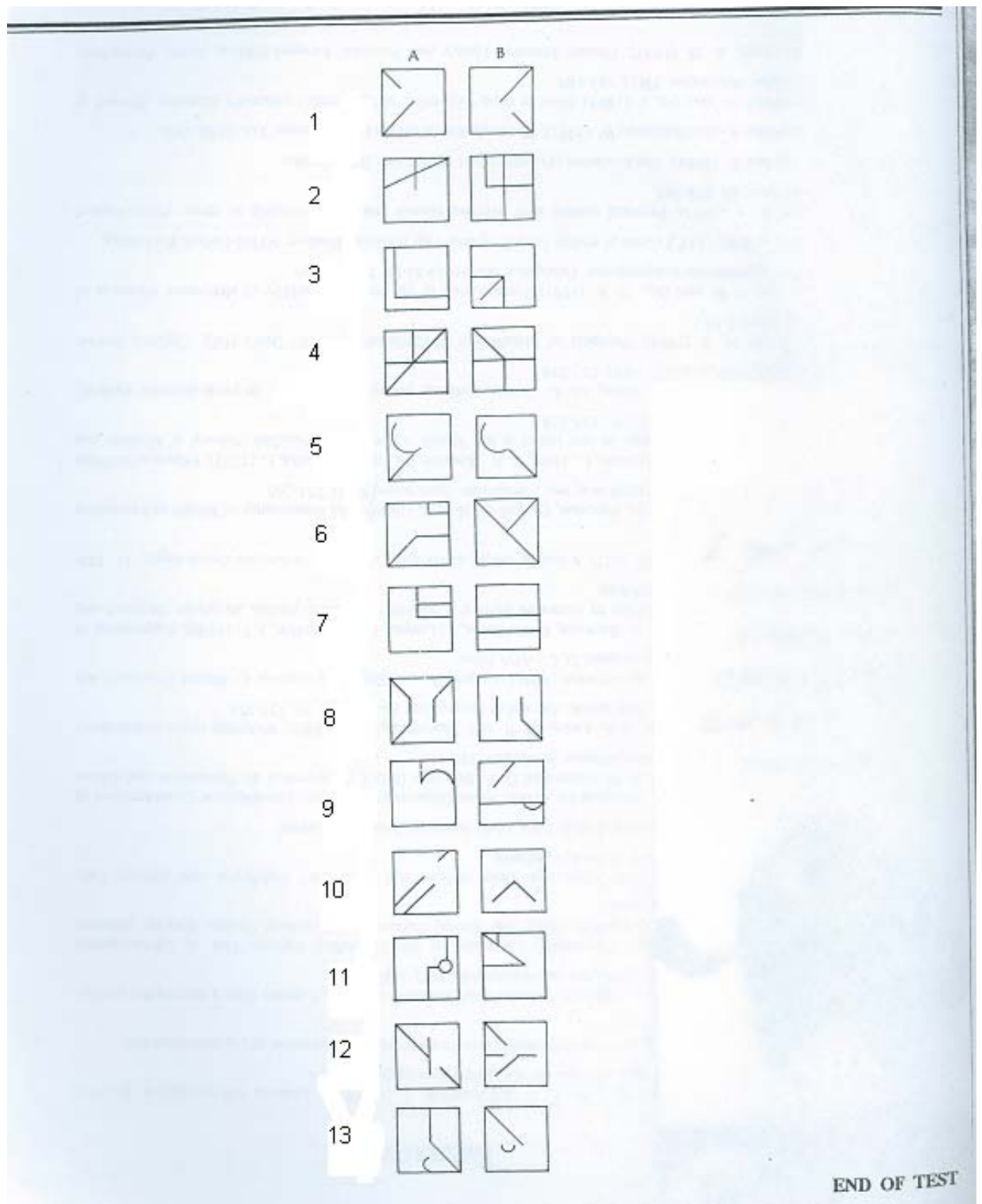
4.  

The correct answers are: 1. - 1 space 2. - 6 spaces 3. - 2 spaces 4. - 3 spaces

PLEASE ASK NOW IF YOU HAVE ANY QUESTIONS OR DO NOT UNDERSTAND WHY THESE ANSWERS ARE CORRECT.

When you are given the signal to start you will have 6 minutes for this test. Remember to work as quickly and accurately as you can. You should mark your answers on the answer sheet provided. If you are not sure of an answer, leave the answer blank as incorrect answers will count against you.

PLEASE DO NOT TURN OVER UNTIL YOU ARE GIVEN THE SIGNAL TO START.



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