Title: The Effects of Redbull on Computer Gaming Ability and other Cognitive Tasks

Dr Patricia Frazer¹, BSc, MSc, PhD.

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Supervisor: Dr Richard Stephens

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School of Psychology
Faculty of Natural Sciences, Keele University

¹ Submitted under the name Patricia Watson. Contact patricia.frazer@dbs.ie.
Abstract

A repeated measures design was used to examine the effect of consuming redbull on computer gaming ability in placebo-controlled experiment. Participants were 21 experienced gamers (18 male, three female), blinded to experimental condition. Outcome measures included performance in a ‘first-person shooter’ at five levels of increasing difficulty, as well as other tests of attentional performance, included to identify specific domains of improvement. A two-way repeated measures ANOVA showed significant effects of drink on gaming performance (F= 7.531, p< .05), but no significant interaction between drink and difficulty level. No significant effects were observed for reaction times or specific tests of attentional performance, so the specific domain through which redbull may enhance computer gaming ability remains unclear.
Introduction

*What are ‘Functional Energy Drinks’, and Why Study them?*

‘Functional energy drinks’, also known as ‘stimulant drinks’ have been growing in popularity since the late 1980s, described by a leading food and drinks marketing consultancy as a sector experiencing dynamic growth (Zenith International, 2005). A Stimulant drinks Committee was established by SafeFood (A food safety promotion board appointed by the Republic of Ireland’s Minister for Health, concerning use of stimulant drinks in the UK and Ireland), and they defined stimulant drinks as “a beverage which typically contains caffeine, taurine and vitamins and may contain an energy source (e.g. carbohydrate) and/or other substances, marketed for the specific purpose of providing real or perceived enhanced physiological and/or performance effects” (Finnegan, 2003, p.148). Since its release in Austria in 1984, Red Bull in particular has gained popularity as a stimulant drink, referred to as “the undisputed market leader” by drinks consultants Zenith International (2005, ¶ 3). Its manufacturers print the claim that the combinatorial effect of its key components, caffeine, taurine and glucuronolactone “improves performance, improves concentration and reaction speed, improves emotional status [and] stimulates metabolism” on every can. Computer gamers have become a new set of core consumers of energy drinks, consuming them to enhance performance in periods of extended play. Red Bull promote the use of their product to enhance computer gaming through sponsorship of local area network (LAN) gaming parties, such as 'Weekend Wars', but no formal assessment has been conducted into the effects of Red Bull on computer gaming to date. The aim of the current study is to experimentally investigate the effects of Red Bull on computer gaming ability. One objective is to study gamers’ performance in its own right; a second is to utilise the computer game as a simulator of real-world performance.
Computer Games and Computer Gamers

In a presidential address on the use of computer games in psychological research Washburn (2003) cites a problem of definition of what constitutes a computer game, and notes that computer-based interaction considered fun or enjoyable by one person may be considered a chore to another. Janz and Martens, in their article concerning the social context of playing computer games, note that all types of computer game share the common element of being “an interactive kind of mediated entertainment” (2005, p. 336). Given such a broad definition of computer game, practically everyone in the developed world could be considered a computer gamer, as the vast majority of us have played a game with a computer interface, whether on our personal computers or gaming consoles.

Interest in gaming has reached such levels that professional ‘cyber-athletes’ can now make a living from playing computer games. Janz and Martens (2005) developed categories of computer gamer based on reported hours per day spent gaming in a sample of 200 attendees of Campzone2, a major LAN event in July 2002. They categorised as ‘heavy gamers’ (39.4% of the sample) as those who spent more than 2.5 hours a day playing computer games, ‘moderate gamers’ (27.7% of sample) spent between 1 hour and 2.5 hours a day and ‘light’ gamers (32.9% of sample) spent less than one hour a day gaming. For the purposes of this study, the concept of being ‘a computer gamer’ was participant-defined. Advertisements for volunteers “interested in computer games” were used to attract participants (see Appendix A for sample poster), and the resultant group of participants fell between the ‘moderate’ to ‘light’ gamers groups, by these definitions.

Using Computer Games to Study Cognitive Psychology

DeGelder and Bertelson (2003) argue that laboratory studies, even those specifically involving multisensory integration, often cannot allow generalization to real-life performance as they reflect response strategies based on the particular demands of the laboratory task,
and do not produce the automatic perceptual responses found in real world challenges. Such real-world challenges are likely to be not only more perceptually complex, but can be affected differentially by motivation. Washburn, Hopkins and Rumbaugh (1989, in Washburn 2003) gave a continuous performance task to a group of 31 undergraduate students, in two formats. Fifteen of the volunteers were asked to watch stimuli presented on a computer screen, responding to the presence of the letter H by hitting a mouse button, and not responding to presentation of the letter X. The remaining sixteen students were presented essentially the same task, but in the form of a star wars game. They were asked to respond to H-shaped ‘enemy ships’, and not to the X-shaped ships of the rebel alliance. Responses were more accurate in the H/X task presentation, but faster in the Star wars game version. This was attributed by the authors to the effects of competition. Factors such as motivation, which may affect performance on tests delivered in a game format, may mediate the effects of agents influencing cognitive performance. This study provides an opportunity to examine the effects of Red Bull on both simple ‘closed’ cognitive tasks and the more complex task of computer gaming.

The Active Ingredients of Red Bull

Caffeine

Of Red Bull's three main ingredients the effects and mechanism of action are best understood for caffeine. Caffeine is a CNS stimulant. It enhances overall cardiovascular function, and its reputation for enhancing physical endurance is such that its use (in concentrations of 12mg/mL or higher) has been banned by the International Olympics Committee (Kim, 2003). Caffeine exerts its psychoactive effects by blocking adenosine receptors. Adenosine is an inhibitory neurotransmitter of the central and peripheral nervous systems, and it's inhibition by caffeine gives a slight overall excitatory effect (Parrott, Morinan, Moss and Scholey, 2004). Acute doses of caffeine produce EEG patterns indicative of cortical arousal and feelings of greater alertness in regular users, who also demonstrate faster responses and greater vigilance in cognitive performance tasks (Brice and Smith, 2001). Smith (2002) reviews
evidence of the effects of caffeine on cognitive performance and concludes that consumption of caffeine results in improved vigilance and better performance on tasks of sustained attention. Numerous studies report improved simple and choice reaction time (Clubley, Bye, Henson, Peck and Riddington, 1979; Haskell, Kennedy, Wesnes and Scholey, 2005; Jarvis, 1992), increased vigilance (Haskell et al. 2005; Regina, Smith, Keiper and Mc Kelvey, 1974) and enhanced attention (Warburton, 1995) after acute administration of caffeine. Though there is a general consensus that administration of caffeine can result in improved performances in cognitive tasks, there is controversy as to whether these effects constitute a 'real' net benefit, or merely represent a reversal of the negative effects of caffeine withdrawal (James, 1994).

The ‘Withdrawal-Alleviation’ Debate

A withdrawal syndrome has long been associated with abstinence from use in regular caffeine consumers. A review by Juliano and Griffiths (2004) concludes that there is sufficient evidence that abstinence in regular caffeine consumers results in a withdrawal syndrome, even when participant withdrawal expectancy is controlled. Empirically validated symptoms include headache, fatigue, decreased alertness, and depressed mood and concentration. These effects have been demonstrated to be time-limited and reversible by acute re-administration of caffeine.

James and Rogers (2005) argue that it is difficult to determine whether the perceived effects of caffeine represent a net benefit, or merely a reversal of withdrawal, as acute caffeine studies have generally been confounded in two ways. Firstly, many laboratory experiments comparing caffeine with placebo require participant pre-trial caffeine abstinence, for example in a study by Bruce, Scott, Lader and Marks (1986) participants were required to abstain from caffeine for 24 hours before testing. This is standard practice in most placebo-controlled trials investigating drug effects. These studies frequently take advantage of natural overnight abstinence, so that by the time testing occurs, participants may have been abstinent for long enough to induce withdrawal. Typical overnight abstinence is 10-14 hours, resulting in 'substantial elimination of systemic caffeine (Lelo, Miners, Robson and Birkett, 1986a,b, cited
in James and Rogers, 2005). In these studies most participants will be in a state of caffeine withdrawal, as most people habitually consume caffeine, so outcomes may represent a reversal of withdrawal in these participants, as opposed to a real acute effect of caffeine administration. Secondly, studies that do attempt to address possible withdrawal effects by controlling pre-study caffeine intake have generally done so by administering a fixed amount of caffeine for all participants prior to the study (e.g. Warburton, 1995). However, withdrawal effects should not be assumed uniform across participants with different caffeine consumption habits. Juliano and Griffiths' (2004) review cites evidence that withdrawal symptoms are related in severity to the magnitude of the habitual caffeine dose. These findings, the authors suggest, "confirm that the withdrawal effect reflects a real pharmacological process" (Juliano and Griffiths, 2004, p11). This means that in uniform pre-dose studies withdrawal may not be fully reversed in some participants; therefore caffeine withdrawal status may still be a confounding factor in interpreting these studies outcomes.

**The Alternating Exposure-Abstinence Model**

James and Rogers (2005) recommend using an alternating exposure-abstinence model to try to separate withdrawal reversal from acute effects. Based on such a model, James (1998) used a placebo-controlled, double blind crossover design where consumption occurred in four patterns: 6 days of placebo, followed by a placebo ‘challenge day’ (called ‘PP’), on which testing took place; 6 days of placebo followed by a caffeine ‘challenge day’(PC) (considered the ‘acute effects’ condition), 6 days of caffeine followed by a placebo ‘challenge day’ (CP), and finally 6 days of usual amount of caffeine followed by a caffeine ‘challenge day’ (CC) (considered to represent an ‘habitual use’ condition). Caffeine and placebo were administered in capsule form, and participants’ normal consumption habits were measured by self-report (cups of coffee per day) prior to the study to allow controlled administration during the caffeine run-in phases, based on levels of regular use, so that withdrawal would be reliably reversed for all participants in these phases. This design was employed because it “permits assessments to be made of both the acute and chronic effects of caffeine, while also controlling for potential confounding due to tolerance and withdrawal effects associated with habitual consumption of the drug” (James, 1998, p 33). No specific hypotheses were stated
concerning the outcome of each experimental condition, however chronic and acute effects of caffeine were compared by looking at the CC and PC conditions, and these effects were also compared to two control conditions (PP - no drug, and CP, withdrawal). On challenge days participants were tested using a character-recognition task to assess information-transfer and short term memory. James found that performance in the CP condition was significantly worse than in the other three conditions (which did not differ significantly from each other). This is presented as evidence that caffeine’s perceived effects represent withdrawal reversal only. Whilst the alternating exposure-abstinence model doubtless provides the best methodological means of separating net gains from withdrawal-reversal, power to detect net benefits was weakened in application in this particular case by the relatively low dose of caffeine administered (1.75mg/kg bodyweight, about half that administered in acute caffeine research) and also the use of only one cognitive test to detect effects. It is possible that differences in effect size between real effects and a larger withdrawal reversal effect are responsible for this result, i.e. it may be the case that the influence of caffeine exerts a smaller (but still significant) effect on performance than a larger, different effect exerted by caffeine withdrawal. Mean performance scores (responses per minute: a composite speed/accuracy outcome) were not reported for each caffeine condition, but are displayed on a line graph, where it can be seen that mean score in the PC (acute) condition is slightly higher than that in the PP condition (control- no caffeine) (James, 1998, p. 37).

Can Only Caffeine-Withdrawn Users Expect to Benefit From Red Bull?

Smith (2002) holds that, for the withdrawal alleviation model to be supported, decrements in performance should be a consistently demonstrated consequence of withdrawal. However, evidence for signs of caffeine withdrawal, such as impaired cognitive performance, is much more ambiguous than that for symptoms (such as headache, fatigue etc., discussed earlier). In their comprehensive withdrawal review, Juliano and Griffiths note that while cognitive detriments have been found using a range of methodologies (including comparing acute with chronic abstinence) only 48% of the behavioural/cognitive effects studies reviewed reported significant impairment on any of the measures used. They conclude “this category is
comprised of heterogeneous measures of performance impairment and, at present, there is not enough information to reach a conclusion about the validity of any specific performance measure” (Juliano and Griffiths, 2004, p. 19). So, though certain symptoms are an empirically validated consequence of withdrawal, this should not be confused with empirical validation of detriments in cognitive performance as a consequence of caffeine withdrawal. Considering this, James and Rogers’ (2005) use of Juliano and Griffiths’ (2004) caffeine withdrawal review to support their withdrawal-alleviation model is slightly misleading.

The results of James (1998) do not provide clear support for a withdrawal-alleviation model of the effects of caffeine on cognitive performance, as he claims. The finding that caffeine enhanced performance only in the ‘PC’ condition (representative of withdrawal) may not actually be contradictory to other studies’ findings of non-withdrawn performance enhancement, it could be that caffeine has withdrawal-alleviation only effects on verbal memory (tested by James, 1998), but dose-dependent enhancing effects on reaction time and vigilance.

Acute improvements have been demonstrated in some studies of non-withdrawn users. Christopher, Sutherland and Smith (2005) put no restrictions on consumption prior to treatment and testing on the regular users who took part in their study. Regular users were randomly assigned to groups who were administered either 2mg/kg caffeine or placebo in a double-blind experiment, use of caffeine prior to treatment was measured by questionnaire and verified by saliva assay. They hypothesised that if the withdrawal-alleviation model of effects were accurate, there should be no difference between placebo and treatment groups in performance (as neither group was withdrawn when treated). They found that performance was enhanced in a categoric search task (selective attention), repeated digits test (visual vigilance) and a simple reaction time task. This study has been criticised by James and Rogers (2005) for two reasons. Firstly, validation of pre-study caffeine consumption showed unusual patterns of caffeine saliva levels. This suggests either very atypical consumption by participants (affecting the generalizability of results) or unreliable saliva assay. Secondly, 15 pairwise comparisons were made on performance and mood measures, with no control for
Type-1 error inflation. Had a Bonferroni correction been applied, then none of the significant results reported would meet corrected significance criteria. However, if the study is interpreted as an exploratory investigation, it indicates that caffeine may have beneficial effects beyond withdrawal alleviation, for certain users. Exploratory research has been described as data gathering designed to minimise Type 2 errors, whilst confirmatory research places more emphasis on minimising type 2 errors (Jaeger and Halliday, 1998). As an exploratory study, it is not unusual that all results do not meet accepted levels of significance, though the results of such should be interpreted with caution.

*Implications for the Current Study*

Considering the literature concerning caffeine’s effects on performance in a range of tasks, Smith concludes “levels of caffeine consumed by most people have largely positive effects on behaviour” (2002, p1243). Though the withdrawal-alleviation debate goes on, sufficient evidence exists to expect improvements in reaction time after administration of caffeine to either habitual consumers or habitual non-consumers. Though an alternating exposure-abstinence design would be most appropriate in differentiating between acute net gains and withdrawal-reversal effects of a caffeinated drink, that is not the aim of the current study, nor would implementation of a design placing such high time demands on participants have been practicable. The aim is to assess whether consuming Red Bull will enhance computer gaming and/or cognitive performance in the manner in which it is commonly used- consumed in the context of regular caffeine consumption habits. Consequently, there were no restrictions on caffeine consumption prior to testing placed on participants in the current study.

*Other Active Ingredients of Red Bull*

The second of Red Bull’s active ingredients, taurine, is endogenous in humans. It is synthesised within neurons, and normally found in high concentrations throughout the brain and skeletal muscles. The extent of taurine’s effects on humans is unknown, but it crosses the blood brain barrier only if concentrations in the brain drop sufficiently low. As such
conditions are unlikely outside of ischemia, its impact on cognitive performance is likely to be limited (Kim 2003). Bakker and Berg, (2002) demonstrated increased force generation during muscle contraction in the skinned muscle fibres of rats in vitro when taurine was added to baths containing a maintenance solution (potassium hexamehtylene-diamine-tetraacytate). It is possible that muscle contractility is facilitated by taurine in humans too, its contribution to the effects of Red Bull are controversial (Kim, 2003). Manual dexterity will be one of the outcome variables included in the study, as enhancement of this skill by Red Bull may have implications for gaming performance through participants’ ability to manipulate keyboard controls. The third active ingredient of Red Bull, Glucuronolactone, is a sugar that occurs naturally within the body. Red Bull company claim that it ‘accelerates the elimination of both endogenic and exogenic noxae’ giving a ‘…detoxifying effect’ (The Red Bull Company, n.d.). These claims have not been substantiated by research and little is known about its effects on cognitive performance (Kim, 2003), however there is no evidence to suggest that any ‘detox’ mechanisms would affect cognitive performance.

Evidence for Red Bull’s Effect on Cognitive Performance

Studies directly investigating Red Bull’s effects on cognitive performance are scarce, and at the time of writing, no studies have been conducted attempting to assess its effects on computer gaming performance. Alford, Cox and Wescott (2000) studied the psychomotor, cognitive and physical effects of Red Bull using a double-blinded, repeated measures design. The 36 participating students were ‘moderate caffeine consumers’ and were not asked to abstain before testing (assumed non-withdrawn). They found a significant improvement in performance on a choice reaction time and a memory task (immediate recall of number lists), and also increased subjective alertness, as measured by a visual analogue scale.

The Effects of other Functional Energy Drinks

Some studies have assessed the effects, not of Red Bull, but of energy drinks with similar
active ingredients (i.e. high caffeine and sugar). Siedl, Peyrl, Nicham and Hauser (2000) compared motor reaction times and emotional well-being of participants given capsules containing caffeine, taurine and glucuronolactone (the three main active ingredients of Red Bull, though without the carbohydrates and B vitamins also present in the drink) with controls in a double-blind placebo-controlled experiment. The sample was made up of even numbers of regular consumers and non-consumers of caffeine, but all were required to be caffeine abstinent for at least 24 hours prior to testing. The experimental group demonstrated significantly shorter reaction times and scored higher on a measure of emotional well-being than controls.

Spectorman, Bhuiya, Kuppuswamy, Strutton, Catley and Davey (2005) found that administration of both caffeine and glucose combined, or caffeine alone, in the form of carbonated drinks significantly increased corticospinal excitability (as measured by motor-evoked potentials) in participants described as having ‘fasted overnight’ (likely to be caffeine withdrawn). The corticospinal tract is the primary output pathway from the motor cortex to the spinal cord (Guyton, 1992), therefore facilitation of its signalling has implications for motor reaction times.

The effect of such ‘energy drinks’ on cognitive tasks has also been studied. Rao, Hu and Nobre (2005) examined performance in a cognitive task involving sustained attention and motor reaction (identification of target in peripherally streaming stimuli) in a group of forty participants blindly assigned to control drink or energy drink conditions. Participants were not required to undergo pre-trial caffeine abstinence. The energy drink used contained caffeine and glucose, and resulted in enhanced behavioural performance in the task, in terms of both speed and accuracy.

So, there is evidence that energy drinks can enhance reaction times in both caffeine withdrawn and non-withdrawn participants. And, indeed, Alford, Cox and Wescott (2000) provide evidence that Red Bull energy drink, in specific, improved choice reaction times and verbal recall in non-withdrawn participants. At the time of writing no energy drink studies were found to suggest that participants must be caffeine withdrawn to benefit form energy drinks, though it should be noted that a limited amount of studies have been conducted in this area.
The Effect of Red Bull in Studies Involving Simulated Tasks

One study has looked at the effects of Red Bull on performance in a computerised simulation of the real-world task of driving, in the hope that observed effects are generalizable to the real world.

Reyner and Horne (2002) found enhanced performance on a driving simulator in sleep-deprived, non-caffeine-withdrawn ‘drivers’ following administration of Red Bull, compared with a control drink. Participants were blind to experimental conditions, and performance was assessed in terms of lower levels of driving ‘incident’ (measured as amount of times ‘lane drifting’ occurred). The amount of incidents was approximately 25% lower in the Red Bull condition. This provides some evidence that Red Bull can enhance performance in complex, real-world tasks as well as simpler lab-based test, but at present this evidence is limited to simulated driving performance.

Arousal as a Mechanism for Red Bull’s Effects

The effects of Red Bull, from those on mood to cognitive and psychomotor effects, fit with a model of increased arousal. ‘Arousal’ can refer to our place or level along four broad continua of activity: gross behavioural states (e.g. waking, sleeping); activity in the peripheral nervous system (e.g. changes in heart rate); changes in brainwave activity; and changes to our subjective emotional or alertness states (Matthews, 2000).

The Yerkes-Dodson Law of arousal states optimum task performance should occur at moderate levels of arousal, as the relationship between arousal and task difficulty forms an inverted u-shaped curve (see figure 1); and that the optimal level for performance in a particular task is inversely related to that task’s difficulty. This law provides only description, however, without a theoretical explanation for such a relationship.
Figure 1. *The Yerkes-Dodson Law: the relation of performance to task difficulty and arousal*

The Easterbrook hypothesis (Easterbrook 1959) attempts to explain the Yerkes-Dodson pattern of response in terms of a narrowing attentional focus. Easterbrook stated that as arousal increases, the focus of attention becomes narrowed. This theory has usually been validated using a ‘dual-task’ method, which involves participants’ simultaneous completion of a primary and a secondary task, while aroused. Generally, as arousal increases, performance on primary tasks is enhanced more than performance in secondary tasks (Eysenck, 1982), consistent with the Easterbrook hypothesis. According to this model, the effect of Red Bull-induced arousal should affect computer game performance differently at different difficulty levels. While Red Bull-induced arousal might be expected to enhance performance at moderate levels of difficulty, a narrowing of attention would be expected to lead to impaired performance at higher difficulty levels.
Aims and Design of the Study

The current study examined the effects of Red Bull on both computer game performance, a complex, real-world type task, and also performance on a range of more specific cognitive tasks that may be considered to be component skills in computer game play. Through measurement of performance on these cognitive tasks under Red Bull and placebo conditions, any potential advantage conferred on game play by Red Bull can be examined more specifically in terms of which particular functions are enhanced.

The Game

The game used was Unreal Tournament 2004, a FPS (First Person Shooter), in which players travel through three-dimensional levels with the object of killing as many virtual enemies as possible in the time provided. This type of game is very popular at LAN parties, (Local Area Network), social gatherings where computer game enthusiasts gather to link up their equipment in order that many players may compete against each other simultaneously. These parties are usually attended by the type of devoted gamers who form the sub-group specifically targeted by energy drinks manufacturers. Janz and Martens (2005) conducted an exploratory survey at a LAN party to investigate the motivation to attend and gaming preferences of gamers in attendance. Sixty five percent of those surveyed expressed preference for first person shooters as a game type and Unreal Tournament was mentioned among the list of favourites. Top of the list was Counterstrike; however this game involves players taking part in counter-terrorists missions, involving a degree of complexity that does not lend itself well to easy comparison of performance under different experimental conditions. Unreal Tournament was chosen as an example of a game popular among the target population (devoted gamers), with a simple outcome variable (number of computer-controlled opponents killed), and easily manipulable difficulty levels. A power analysis using means and standard deviations from pilot work, where an effect size of d=0.73 was observed on computer gaming performance suggested that a sample size of approximately 30 participants was ideal to give sufficient power (1-b=.80, a=.05).
Cognitive Tests

Simple and complex reaction time was measured, as reacting quickly to stimuli is an important factor in this type of game, and because Red Bull Company specifically indicate enhanced reaction time as a benefit of consuming their product. The ability to respond rapidly in different ways to different stimuli, and ability to suppress inappropriate responses was also measured. Both short and long term spatial memory was assessed. Spatial memory may be important in successfully navigating the 3-dimensional world in which game play takes place. Manual dexterity was measured; it is expected to affect game play as the buttons must be pressed rapidly and accurately for successful interaction in the virtual world.

Participants were informed that the purpose of testing was to study the effects of consuming energy drinks and game-playing on mood, in order to blind them to the true outcome variables of interest, in an attempt to control for the potential effects of competitiveness or performance anxiety under experimental conditions. To this end the participants will be administered the ‘state anxiety’ section of the Spielberger STAI (State-Trait anxiety questionnaire, Spielberger, 1983) after testing.

Hypotheses

The Unreal Tournament game readily allows manipulation of difficulty level via user settings. ‘Difficulty’ is increased by increasing the accuracy and speed of the computer-controlled enemy ‘bots’ who form players enemies to be avoided and targets to be killed. The five highest difficulty levels were used. These are designed to cater for experienced gamers. If Red Bull exerts its beneficial effect by increasing arousal, the Easterbrook hypothesis predicts narrowing of attention will impair performance at high difficulty levels of gaming in the Red Bull condition. Therefore an interaction effect is predicted such that the positive effect of Red bull on performance will be of greater magnitude in the easier levels of play than the more difficult levels.

Formally, the experimental hypotheses are: 1) that Red Bull will enhance performance in Unreal Tournament, demonstrated by higher mean kill scores in the Red Bull condition than in the control condition 2) Conforming to the Easterbrook hypothesis, there will be an interaction effect on Unreal Tournament performance between arousal (Red Bull/ placebo) and difficulty
level such that the magnitude of the enhancing effects of Red Bull will be smaller at higher
difficulty levels of game play 3) That performance on some of the cognitive tests will also be
enhanced in the Red Bull condition, demonstrated by shorter mean reaction times and higher
accuracy.
Method

Participants

An opportunity sample of 21 adults (18 male, 3 female) who regularly play computer games was recruited from staff and students of Keele University by email, and from the general public through advertisements. Participants ranged in age from 18 to 35 years, with a mean age of 24.3 years (standard deviation 3.64 years). Entrance in a raffle with a computer game store gift voucher as a prize was offered as an incentive for participants to take part. Participants were each asked about their familiarity with the game (Unreal Tournament 2004), which computer games they play most, and to estimate the average amount of hours they spend gaming weekly. Self-reported hours spent gaming weekly ranged from 0.5 to 14 hours, mean hours gaming per week was 5.5 hours. The computer games played included role playing games, puzzle games (e.g. Tetris) and other First Person shooter games. One participant reported playing Unreal Tournament regularly.

Stimuli

Game

The computer game Unreal Tournament 2004 (© Epic Games, 2004) was employed, a game in which players negotiate virtual 3-dimensional spaces, the object of which is to shoot computer-controlled opponents. Game playing took place in the 3-dimensional level map called 'DM-ASBESTOS'- an industrial-style area spanning three floors, containing tunnels, ramps, small water pools and a lift. The aim of this game is to kill as many as possible of the computer-controlled enemy 'bots'. These enemy targets are all other characters appearing on screen (i.e. no 'friendly' characters appear in this game mode). The number of 'bots' present in each level, and the
degree of skill they display is controlled automatically by the game software according to the
difficulty level, thus opposition skill can be considered equal for all participants.

**Drink**

The Red Bull drink consisted of one 250ml can of Red Bull, containing 80mg of caffeine
(approximately equal to a weak cup of filter coffee).

The control drink used was adapted from that used by Alford, Cox and Wescott (2000). It was also
administered as a 250ml serving, and was made up of 12 parts soda water to 3 parts lime
concentrate, 3 parts apple concentrate and 1 part blackcurrant concentrate, and was as similar as
possible in taste to Red Bull, with no taurine, caffeine or glucuronolactone.

**Tests of Attentional Performance**

The computerised reaction time tasks *Flexibility, Go/Nogo* and *Alertness* subtests of the Tests for
Attentional Performance (Zimmermann and Fimm, 1995) were used. In the Flexibility test
participants are simultaneously presented with a letter on one side of the screen and a number on
the other. Their task is to switch between responding to the letter side and the number side of the
screen for each presentation by touching the 1 button for the left side and 2 button for the right
(see Figure 2). This tests participants’ ability to respond differently to different stimuli at a rapid
pace, and also participants’ ability to suppress inappropriate responses.
Figure 2. Representation of the Tests for Attentional Performance screen during the Flexibility test

The Go/No-go test required participants to recognise and respond rapidly to two out of five previously demonstrated patterns presented on-screen, by pressing the number one touch button (see Figure 3).

Figure 3. Representation of the Tests for Attentional Performance screen for the Go/Nogo test
This tested participants’ ability to suppress inappropriate responses and to rapidly process information, as they quickly assessed whether each pattern presented was a member of the target set. The Alertness test required participants to respond rapidly as soon as they detected the presence of a cross on the screen under two conditions; simple presentation of the cross and presentation of the cross preceded at irregular intervals by an auditory signal (a ‘beep’). This tests simple reaction time.

Other Cognitive Tests

The Stimuli used for the spatial span test were block tapping patterns of increasing length, administered on a spatial span board (see Apparatus). Different modes of pattern demonstration were used to test short and long term spatial memory (see Procedure). The Finger Tapping test involved recording the number of presses on a push-button counter (see Apparatus and Procedure) as a measure of the participants’ manual dexterity.

Apparatus

Unreal Tournament was run on a desktop computer, to the following specifications:

Intel (R) Celeron (R) CPU 3.06GHz processor and 3.07 GHz of RAM, with a flat screen monitor and using a 5v 100mA Microsoft USB-compatible optical mouse and mouse pad.

The Tests of Attentional Performance were run on a desktop computer with a DOS operating system (Zimmermann and Fimm, 1995) using a software programme floppy disk with corresponding dongle and 2 numbered touch buttons. These very sensitive touch pad buttons were
used by participants to make their responses during testing, which were recorded by the program onto the hard disk of the computer.

For the manual dexterity test a stopwatch and a metal push-button counter were used. For the Spatial Span tests- Forward, Backward and Long-term (Lezak, 1995) a spatial span board, with blue blocks numbered from 1-10 was used (pattern of block layout and example instruction sheets can be found in Appendix A).

*Design*

Design differs for the gaming and cognitive tests sections of the study.

*Gaming*

A fully related two x five factorial design was applied. The first factor, drink, had two levels (Red Bull/Placebo). The second factor was game difficulty setting, with five levels, from easy to difficult, as follows; 'Skilled', 'Adept', 'Masterful', 'Inhuman', 'Godlike'. The dependent from the computer game performance was number of kills (in each level). Kills are the number of computer controlled players ('bots') killed by each player.

*Cognitive Tests*

A one-way related design was used. The drink factor had two levels, Red Bull and Placebo, and the dependent variables were mean reaction time and percentage accuracy for each of the three TAPs tests used (alertness, flexibility and go/no-go), mean amount of taps for each hand for the manual dexterity test, and score for the forwards, backwards and long-term spatial span tests.
The order in which participants experienced the six tests [manual dexterity; computer game play (all five levels); spatial span (forwards, backwards then long-term), flexibility, alertness and go/no-go] was randomised using an on-line random number generator (Urbaniak and Plous, 1997).

Procedure

Participants completed consent forms and gave information concerning usual consumption of caffeine (see Appendix A for examples of the consent form and demographics questionnaire) before being administered a drink. The order of administration of Red Bull or placebo was determined by flipping a coin before each participant’s first testing session. Time between testing occasions was determined by participant availability and ranged from 21 hours to 38 days. Participants then read a newspaper for 30 minutes whilst waiting for the drink to take effect, as caffeine reaches peak plasma concentrations between 30-60 minutes after ingestion, and its psychoactive effects are usually observable during this time frame (Parrott, Morinan, Moss and Scholey, 2004). Also, the Red Bull Company advises that the optimum effects of its product are seen 30 minutes after ingestion. Participants completed all tests on both occasions in testing sessions that lasted approximately one hour on each occasion.

Blinding

Both drinks were administered in an identical opaque cup. As well as adding 25ml of quinine water to each drink to help mask the flavour, a strong tasting breath-freshening strip was administered prior to drink consumption in both conditions to help further mask the flavour of the drinks. Guesses concerning the drinks ‘Red Bull’ or ‘Other’ by participants were recorded just after drinking, before testing began.
Testing
Participants always completed the STAI anxiety-state questionnaire (Speilberger, 1983) last, to maintain their conception that the real aim is to investigate the effects of the other tasks on this variable.

Unreal Tournament play:
Participants played 5 5-minute ‘instant action deathmatch’ games (1 at each of the five levels of difficulty). The aims of the game were explained to each participant verbally, and participants all offered the opportunity to change the configuration of controls, and to have a short practice (1 minute at the ‘skilled’ level) to ensure familiarity with controls. Participants were blinded to difficulty level being played, so after each five minute play interval, participants were asked to leave the testing room whilst difficulty level was changed. During this time screenshots of player performance statistics for each level will be taken and saved as records of score.

Tests of Attentional Performance
After presentation of written on-screen instructions, each participant completed standardised pre-tests until both they and the experimenter were sure the objectives of the test were understood. The creation of participant files before each testing session allows reaction times and amount of correct responses, omissions, false alarms and ‘lapses’ (outliers) to be saved to the hard drive. The outcome variables for all these tests were reaction time (time from presentation to response in milliseconds) and percentage accuracy.

Manual Dexterity
Participants were required to push the button on the counter with their thumb as rapidly as possible for ten separate five-second trials - five on each hand. Participants began with the right hand and alternated right to left, and turned a knob to reset the counter between each trial. Amount of button pushes for each trial was recorded, mean amount of button pushes for each hand was the relevant
outcome variable.

**Spatial Span**

Participants were given the instructions ‘Now I want you to do exactly as I do, touch the blocks I touch in the same order’ before being administered the increasingly long block tapping patterns of the Spatial Span Forwards test first. Two trials were administered for each pattern length; the test was discontinued when the participant failed both trials of a pattern length. The participant’s spatial span is the maximum length of blocks in a pattern successfully copied in at least one trial. The Forwards test was followed by administration of the Backwards Spatial Span test, in which participants were required to tap out the reverse of the pattern demonstrated by the experimenter. The Long Term Spatial Span test was always administered third. In it participants were required to attempt to accurately copy block-tapping patterns that were one block longer than the participant’s spatial span. Demonstration of each pattern was repeated 8 times to allow participant’s ability to memorise with repeated exposure to be tested. The outcome variable for each of these tests was score, with one point awarded for each pattern trial correctly repeated.

**Consent**

Informed written consent was sought from all participants before taking part in the study. They were informed at consent stage of their right not to take part, or to withdraw at any time. Participants were informed that participation would involve consuming beverages, one of which is Red Bull ‘energy drink’, containing taurine, caffeine and glucuronolactone. Participants were given a description of the testing procedures they would be expected to partake in before giving consent (see Appendix A for sample consent forms). The study was given approval by the Keele University School of Psychology Research Ethics Committee.
Results

Data was analysed using SPSS (Statistical Package for the Social Sciences) version 14.0.

Gaming

Hypotheses one and two were tested in this section. The effects of two factors, drink and difficulty level on computer gaming performance (as measured by number of kills) was examined.

The total number of computer-controlled ‘bots’ killed by participants in each difficulty level was recorded after each five-minute match. The kills scores in each difficulty level were added for each drink condition to give total number of kills in the Red Bull and in the Placebo conditions. Mean number of kills in each difficulty level and total in Red Bull and placebo conditions are displayed in Table 1.

Table 1
Means and standard deviations of the number of kills in each difficulty level for each drink condition.

<table>
<thead>
<tr>
<th>Difficulty level</th>
<th>skilled</th>
<th>adept</th>
<th>masterful</th>
<th>inhuman</th>
<th>godlike</th>
<th>drink total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Bull</td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.10</td>
<td>4.0</td>
<td>2.29</td>
<td>1.81</td>
<td>1.71</td>
<td>15.90</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.77)</td>
<td>(3.16)</td>
<td>(2.49)</td>
<td>(1.66)</td>
<td>(3.22)</td>
<td>(1.40)</td>
</tr>
<tr>
<td>Placebo</td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>3.05</td>
<td>2.05</td>
<td>0.95</td>
<td>0.95</td>
<td>13.05</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5.74)</td>
<td>(2.52)</td>
<td>(2.18)</td>
<td>(0.92)</td>
<td>(1.16)</td>
<td>(9.29)</td>
</tr>
<tr>
<td>Level</td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.95</td>
<td>6.5</td>
<td>3.5</td>
<td>2.7</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6.82)</td>
<td>(4.17)</td>
<td>(1.93)</td>
<td>(1.95)</td>
<td>(1.73)</td>
<td></td>
</tr>
</tbody>
</table>
Kills data were explored to assess their satisfaction of ANOVA's assumptions. As can be seen from Table 2, the data were not normally distributed. The skewness and kurtosis statistics given by SPSS were converted to z scores by dividing each skewness and kurtosis statistic by its standard error. Conversion of these values to z scores standardises them, allowing one to determine if the distribution of kills scores differs significantly from normal. In a completely normal distribution, $z_{skewness}$ and $z_{kurtosis}$ would be 0, $z_{skewness}$ or $z_{kurtosis}$ of over 1.96 differ significantly from normal at $p < .05$, over 2.58 at $p < .01$, and $z_{skewness}$ or $z_{kurtosis}$ of over 3.29 suggest the distribution differs highly significantly from normal, at $p < .001$.

After such a conversion, it could be seen that kills data were positively skewed and displayed a leptokurtic distribution. The value of the $F_{max}$ ratio for difficulty level (comparing variance in the differences between treatment levels) was 11.43, indicating that the data did not meet the sphericity assumption. $F_{max}$ for the drink factor was 1.51, so variance was sufficiently homogenous for the drink factor.

Table 2

*Skewness and Kurtosis z scores for kills data in each difficulty level, for each drink condition*

<table>
<thead>
<tr>
<th>Difficulty level</th>
<th>Drink</th>
<th>skilled</th>
<th>adept</th>
<th>masterful</th>
<th>inhuman</th>
<th>godlike</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red Bull</td>
<td>skewness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.41</td>
<td>1.55</td>
<td>6.33</td>
<td>1.53</td>
<td>2.27</td>
<td>3.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.84</td>
<td>0.50</td>
<td>12.58</td>
<td>0.29</td>
<td>16.41</td>
<td>4.43</td>
</tr>
<tr>
<td></td>
<td>Placebo</td>
<td>skewness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.27</td>
<td>1.41</td>
<td>3.64</td>
<td>1.05</td>
<td>1.47</td>
<td>2.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.58</td>
<td>-0.05</td>
<td>4.36</td>
<td>-0.69</td>
<td>-1.06</td>
<td>2.85</td>
</tr>
</tbody>
</table>
Participants’ kills scores were converted into z scores, allowing identification of outlying scores in case number 4. The z score for this participants’ total kills in the Red Bull condition was 3.17, and for total kills in the placebo condition it was 3.01, which placed them within the range where we would expect to find 1-0% of scores in a normal distribution. Z scores for this participant in the *masterful* and *godlike* difficulty levels in the Red Bull condition exceeded 3.29, which made them significant outliers (z scores= 3.90 and 4.12, respectively). Exclusion of this case brought z scores of the skewness and kurtosis statistics closer to the normal range, but scores in the godlike difficulty level in the Red Bull condition were still significantly positively skewed, z skewness= 2.37. Excluding case 4 data, $F_{max}$ remained very high at 8.47, indicating that sphericity was still not present. When data from the remaining 20 cases were transformed by adding 1 to each score (to eliminate values of 0) and then taking the natural log of this value ($\ln(x+1)$) kills data were much more normally distributed, as can be seen from the skewness and kurtosis z scores in Table 3. The $F_{max}$ ratio of variance of the differences between difficulty levels for the log transformed data was 2.32, and $F_{max}$ for the drink factor was 1.08 after this transformation.
Table 3

**Skewness and Kurtosis z scores for ln (kills+1) in each treatment condition**

<table>
<thead>
<tr>
<th>Difficulty level</th>
<th>Drink</th>
<th>skilled</th>
<th>adept</th>
<th>masterful</th>
<th>inhuman</th>
<th>godlike</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Bull</td>
<td>skewness</td>
<td>-1.98</td>
<td>-1.13</td>
<td>-1.12</td>
<td>-0.16</td>
<td>0.43</td>
<td>-0.24</td>
</tr>
<tr>
<td></td>
<td>kurtosis</td>
<td>0.83</td>
<td>-0.43</td>
<td>0.21</td>
<td>-1.27</td>
<td>-0.88</td>
<td>-0.48</td>
</tr>
<tr>
<td>Placebo</td>
<td>skewness</td>
<td>-0.89</td>
<td>-1.07</td>
<td>-0.32</td>
<td>0.06</td>
<td>0.65</td>
<td>-0.45</td>
</tr>
<tr>
<td></td>
<td>kurtosis</td>
<td>-1.35</td>
<td>-0.81</td>
<td>-0.97</td>
<td>-1.61</td>
<td>-1.75</td>
<td>-1.08</td>
</tr>
</tbody>
</table>

A repeated measures ANOVA using the ln('kills' +1) data showed significant effects of drink and level, but not drink x level interaction, whether the analysis is conducted with or without data from the outlying high-kills-scorer in case 4. Results of the ANOVA including all 21 cases are shown in Table 4 (SPSS output for repeated measures ANOVA of ln(kills+1) data excluding case 4 can be found in Appendix B).
Table 4

ANOVA summary table for the effect of drink x level on ln(kills+1).

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink</td>
<td>2.227</td>
<td>1</td>
<td>2.227</td>
<td>7.531</td>
<td>.013</td>
</tr>
<tr>
<td>Error (drink)</td>
<td>5.915</td>
<td>20</td>
<td>.296</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>31.682</td>
<td>4</td>
<td>7.920</td>
<td>25.972</td>
<td>.000</td>
</tr>
<tr>
<td>Error (level)</td>
<td>24.397</td>
<td>80</td>
<td>.305</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drink*Level</td>
<td>.182</td>
<td>4</td>
<td>.046</td>
<td>.134</td>
<td>.969</td>
</tr>
<tr>
<td>Error (drink*level)</td>
<td>27.204</td>
<td>80</td>
<td>.340</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hypothesis three was tested in this section. Hypothesis 3 predicted an effect of drink on performance in some or all of the cognitive tests and the test of manual dexterity. Altogether there were 12 outcome variables of interest here: separate reaction time and accuracy scores for each of the three attentional performance tests, a separate accuracy score for each subtest of the Spatial Span test (Forwards, Backwards and Long term), and a separate finger tapping speed score for preferred hand, non-preferred hand, and an average of both hands. Although many comparisons are therefore being made, no correction to the significance criterion to control for type-1 error inflation was made, as these comparisons were used to simply help identify possible sources of gaming improvement for future investigation.

Tests of Attentional Performance

Table 5 shows the mean reaction time and the mean percentage accuracy in the Red Bull and Placebo conditions for each of the three tests of attentional performance. Reaction times were measured in milliseconds, and accuracy score given as the percentage of accurate to inaccurate responses.
### Table 5

**Mean reaction time in milliseconds and percentage accuracy in alertness, go/nogo and flexibility tests in each drink condition**

<table>
<thead>
<tr>
<th>Drink</th>
<th>Alertness</th>
<th>Go/Nogo</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>Accuracy</td>
<td>RT</td>
</tr>
<tr>
<td>Red Bull</td>
<td>208.70</td>
<td>95.82</td>
<td>453.31</td>
</tr>
<tr>
<td></td>
<td>(31.35)</td>
<td>(2.75)</td>
<td>(43.33)</td>
</tr>
<tr>
<td>Placebo</td>
<td>227.18</td>
<td>96.98</td>
<td>456.33</td>
</tr>
<tr>
<td></td>
<td>(65.21)</td>
<td>(1.62)</td>
<td>(52.88)</td>
</tr>
</tbody>
</table>

Data were not normally distributed on some of the attentional performance outcomes variables: Alertness reaction time data, Go/nogo reaction times and Flexibility percentage accuracy scores were all significantly skewed and alertness reaction time data had a high $F_{\text{max}}$ ratio, as can be seen from Table 6. These skews proved resistant to several transformations ($\ln(x)$, $x^2$, $\sqrt{x}$, $1/\text{reversed}x$).
Table 6

$F_{\text{max}}$ ratios for the alertness, Go/Nogo and Flexibility tests and Skewness and Kurtosis z scores in each drink condition

<table>
<thead>
<tr>
<th>Drink</th>
<th>Alertness</th>
<th></th>
<th>Go/Nogo</th>
<th></th>
<th>Flexibility</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>Accuracy</td>
<td>RT</td>
<td>Accuracy</td>
<td>RT</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Red Bull</td>
<td>skewness</td>
<td>0.69</td>
<td>-3.76</td>
<td>-2.34</td>
<td>-0.96</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>kurtosis</td>
<td>-0.73</td>
<td>4.73</td>
<td>1.13</td>
<td>-1.10</td>
<td>-1.17</td>
</tr>
<tr>
<td>Placebo</td>
<td>skewness</td>
<td>5.34</td>
<td>-1.77</td>
<td>-0.35</td>
<td>-1.61</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>kurtosis</td>
<td>9.51</td>
<td>1.59</td>
<td>-0.96</td>
<td>0.57</td>
<td>0.12</td>
</tr>
<tr>
<td>$F_{\text{max}}$</td>
<td>4.33</td>
<td>2.89</td>
<td>1.49</td>
<td>1.77</td>
<td>1.87</td>
<td>1.46</td>
</tr>
</tbody>
</table>

Though exclusion of cases contributing to the high skewness and kurtosis values above improves the distribution so that it conforms more to normality, all cases but one were retained for analysis for several reasons. Firstly, most were outliers to the extent that they had z scores higher than 1.96 (expected of only 5% of a normal population), but a definition of outliers as those with z scores over 2.58 as been suggested as a more suitable cut-off for a small sample (Field, 2005). Secondly, parametric tests are considered robust to violations of their assumptions (Coolican, 2004). Thirdly, and most importantly, because the cognitive tests were only included to investigate factors contributing to improved performances in the computer gaming task, data from all participants whose gaming performance was tested should be included in the cognitive analysis. Case 6 was excluded from analysis of the alertness reaction time data. This participant’s mean reaction time in the placebo condition had a z score of 3.59987, putting it outside any scores expected in a normal distribution around the group mean. Considering the very large size of this z score, and the participant’s performance within the
normal range on the other reaction time tests, it is very likely that this score represents an anomaly such as the participant pressing the touch button too lightly on this testing occasion, and it was excluded on this assumption.

Repeated measures ANOVAs were conducted on each of the six TAPs outcomes, but none were significant.

Other cognitive tests

Means and Standard deviations of the scores on each of the Spatial Span sub-tests (Forwards, Backwards and Long-term) and the three outcomes of the manual dexterity task (Finger Tapping scores for Preferred hand, Unpreferred hand and Both hands) are displayed in Table 7.

Table 7

Means and Standard deviations of Spatial Span and Finger Tapping scores in each drink condition

<table>
<thead>
<tr>
<th>Drink</th>
<th>Spatial Span (number of trials imitated correctly)</th>
<th>Finger Tapping (number of button presses)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forwards</td>
<td>Backwards</td>
</tr>
<tr>
<td>Red Bull</td>
<td>mean</td>
<td>8.62</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(1.72)</td>
</tr>
<tr>
<td>Placebo</td>
<td>mean</td>
<td>8.14</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(2.17)</td>
</tr>
</tbody>
</table>
Scores in the spatial span test were normally distributed and variance was homogenous ($F_{\text{max}} < 3$). Repeated measures ANOVAs for effect of drink on each of these subtests, Forwards, Backwards and Long-term, failed to reach significance. Finger Tapping scores were approximately normally distributed (slightly skewed in the unpreferred hand, red bull condition $z_{\text{skewness}} = 2.07$), and variance was homogenous ($F_{\text{max}} < 3$) for ‘Preferred hand’, ‘Unpreferred hand’ and ‘Both’. Repeated measures ANOVAs for effect of drink on Finger Tapping preferred hand, unpreferred hand and both hands all failed to reach significance.
Blinding

The effectiveness of the drinks condition blinding procedure was assessed using a Pearson’s chi-squared test. The two variables making up the 2x2 contingency table, Table 8, are drink order—whether the participant received Red Bull or Placebo in their first session, and guess—whether the participant guessed that they had Red Bull or Placebo in the first session. There was no significant relationship between drink administered and guess, suggesting that the blinding was successful, $x^2(1, N=21)=1.037, p=.284$.

Table 8
Two x two contingency table showing expected and observed frequencies of drink guesses

<table>
<thead>
<tr>
<th>Participant guess</th>
<th>Drink</th>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red Bull</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>(expected)</td>
<td>(6.9)</td>
<td>(5.1)</td>
</tr>
<tr>
<td></td>
<td>Placebo</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>(expected)</td>
<td>(5.1)</td>
<td>(3.9)</td>
</tr>
</tbody>
</table>
Discussion

*Effects of Red Bull on Computer Gaming*

Based on the results of the computer gaming analysis, Hypothesis 1 was retained. As predicted, Red Bull significantly improved computer gaming performance, measured by total amount of kills over five difficulty levels played under each drink condition (Red Bull/Placebo). Hypothesis 2, however, was rejected. Though the effect of difficulty level on number of kills was highly significant \( (p < .001) \), there was no significant interaction between difficulty level and drink condition, as had been predicted, based on the Easterbrook model of arousal. One possible explanation for this finding is that though manipulation of difficulty level was in one sense successful because it yielded differences in performance, the range of difficulty covered may not have been wide enough to demonstrate the interaction effect predicted. Looking once again at the Yerkes-Dodson pattern of performance and arousal (see Figure 4), the difficulty levels covered may have been representative only of the flattening out at the top of the curve. This is an unlikely explanation as the difficulty levels used ranged up to level five- ‘godlike’, where 50\% of participants scored 0 kills in the placebo condition, and the mean number of kills scored for participants included in the analysis was 1. Alternatively, if it was the case that the interaction was not detected because the difficulty levels used were too difficult, and representative of only the hardest end of the difficulty curve in Figure 2, no improving effect of Red Bull was likely to have been detected at all.
Another possible explanation of the failure to detect the predicted interaction is that the task increased in difficulty in such a way that an arousal-induced narrowing of attention did not hinder performance. While computer gaming involves navigation of a complex virtual world, the task of playing an ‘instant deathmatch’ (the game type used in this case) is relatively simple in terms of objectives: firstly- kill as many enemy ‘bots’ as possible; secondly- don’t die. There are no ‘friendlies’ to avoid, and difficulty is manipulated by increasing the speed and accuracy of the ‘bots’ and the amount of accurate shots from the player necessary to kill them. It is possible that with use of a different type of game, such as a role-playing game, a drink x difficulty level interaction effect might be observed, by manipulating difficulty in a way that involves clear increases in complexity.

An alternative explanation for the Yerkes-Dodson pattern of performance and arousal is put forward by Humphreys and Revelle (1984). They suggest that arousal might affect different
cognitive processes differently. Specifically, they suggest that arousal enhances *sustained information transfer* (the processing of stimuli and executing an associated response, such as in a simple reaction time task), while having a detrimental effect on short term memory. Since the complex tasks used to demonstrate the Yerkes-Dodson effect often involve both abilities, the optimum level of arousal for each task is the level involving the most even trade-off of these abilities. In simple tasks, enhanced reaction times lead to steep increases in performance which are unimpeded by detriments to short term memory abilities, but manipulations increasing the ‘difficulty’ of tasks often also involve increasing loads on short term memory, and so detriments here then become apparent in poorer performance. To be fully supportive of this model, the current study would have been expected to demonstrate a detrimental effect of arousal on memory, and this was not the case with the spatial memory task used. However, it should be noted that the study was not designed with the intention of distinguishing which of these models best explains the Yerkes-Dodson effect. The design was intended to help discern whether Red Bull significantly improves computer gaming and begin to develop a pattern of its cognitive effects that might relate to this area, therefore conclusions concerning which model best explains the Yerkes-Dodson effect cannot be made based on these results.

Another factor to keep in mind whilst considering the possible implications of these results for arousal-based models of action is the issue of blinding. The chi-squared test result, which seems to suggest that since there was no significant relationship between the drink administered and the participants guess, blinding must have been successful, should be interpreted with caution. An expected cell frequency count of <5 (3.9, see Table 7, *Results*) in one of the cells means that the power of the test to detect real effects has been diminished. It may be that participants realised that they had been administered Red Bull through detection of proprioceptive changes, and that
this improved confidence and/or motivation, or brought other confounding factors to bear on computer gaming performance.

**Manual Dexterity**

There is also no evidence to suggest that facilitation of button-pressing/keyboard manipulation through increased manual dexterity contributes to improved performance. Inclusion of this outcome measure was in part inspired by evidence that taurine, an ingredient of Red Bull, facilitates muscle contractility (Bakker and Berg, 2002, see introduction). As taurine is a *conditionally essential* amino acid (essential to the body under specific conditions) whose levels are critically self-regulated within the body, a dietary boost of taurine has potential to enhance muscle contractility only during periods of high physical demand which cause levels to drop significantly. While the tasks of the study were cognitively challenging, participants remained seated throughout, and physical demands were limited—this is turn may have limited the potential of the Red Bull to enhance manual dexterity.

**Reaction Time**

Evidence concerning the role of quicker reaction times as a mechanism of improved computer gaming performance in this study is ambiguous. While effects of Red Bull on reaction times failed to reach significance in this study, a comparative look at mean reaction times under both conditions (see Table 6, *Results*) suggests that an effect may have been present, but have remained undetected due to limited statistical power. A power analysis was conducted which indicated that at least 30 participants should be tested to detect the large computer gaming effect indicated by pilot
work (see introduction). But, energy drinks may have only a medium or small effect on reaction time, which may necessitate the use of samples even larger than 30 to give sufficient power. However, because of difficulties in recruitment (generally due to high time demands on participants and recruitment from a special population, i.e. gamers) and the attrition of two participants who did not return for a second session, only 21 participants completed both testing sessions and were eventually included in analysis. This ‘lack of power’ interpretation of reaction time results is enhanced by previous findings that administration of caffeine improves reaction time in non-caffeine-withdrawn participants (Christopher et al. 2005; Haskell, Kennedy, Wesnes and Scholey.

**Effects on Memory**

Most studies of caffeine’s effects on memory have involved verbal learning tasks, and many have found no effect (Smith, 2000). In this case spatial memory was tested as a potential contributor to computer game skill, because playing modern computer games involves navigation through complex virtual worlds. Mean scores were marginally higher in the Red Bull condition for Forwards and Backwards Spatial Span (see Table 7, Results), so it may be that there was insufficient power to detect a significant effect on these tests, but this study provides no real evidence that computer gaming performance was enhanced by improvements in this domain specifically. This study provides no real evidence that Red Bull has an effect on long or short term spatial memory at all.

**Computer Gaming as a simulator**

Improved computer gaming performances are an unsurprising result in terms of the literature concerning the effect of energy drinks and caffeine on simulated tasks. Both have been
demonstrated to significantly improve performance in computer driving simulators (Regina et al. 1974; Reyner and Horne, 2002).

*Computer Gaming as a Complex Task*

The caffeine literature is inconclusive concerning its effects on ‘higher’ cognitive processes, amongst which many reviewers place verbal memory (Smith, 2000). Putting aside the debate on whether perceived effects are due to withdrawal-alleviation or a real net benefit, James and Rogers note that “one trend evident in the literature is that complex higher-level cognitive processes have generally been reported to be less responsive to caffeine than more simple, repetitive and prolonged psychomotor activities” (2005, p.1). Smith (2000) postulates this may be due to a smaller effect of caffeine on higher processes than that on reaction times and other simple functions. This hypothesis is at odds with the findings of this study, where a sample of sufficient power to detect an effect on a complex task (computer gaming) failed to establish significant effects on simple reaction time tasks. There are two possible explanations for this. Firstly, the terms ‘complex’ task and ‘higher’ function are vague, so studies grouped under these umbrella terms may involve very different measures, measuring many different constructs, and therefore shouldn’t be expected to show the same pattern of effects. In contrast to studies using verbal learning as a ‘complex task’, Lyvers, Brooks and Matica (2004) employed a between subjects, single blind design to study the effect of a 300mg dose of caffeine on performance in the Wisconsin Card Sorting Test, a commonly used test of executive function. They found that caffeine significantly improved performance in this complex task in regular low caffeine consumers, but not high regular consumers. The lack of effect in high consumers is likely accountable for by the required pre-trial 15hour abstinence from caffeine leaving high regular users considerably
withdrawn. So, finding significant improving effects of caffeine on performance in complex tasks in non-withdrawn participants (such as in the present study) does have precedent in the literature.

Secondly, the effects of Red Bull may differ from those of caffeine alone. In contrast to evidence from caffeine studies, Alford, Cox and Wescott found that Red Bull significantly improved memory using a task testing supposedly ‘higher’ cognitive functions: a verbal recall test, in double-blind placebo controlled trial that imposed no pre-trial caffeine restriction (2000).

Conclusions and Implications of findings

The use of computer simulators in research has been criticised on the grounds that it represents a simplification of real-world experience, making generalisation to everyday experience difficult (Washburn, 2003). However, psychologists at the 1999 symposium on ‘Computer Games in Psychological Research’ suggested that the use of computer games in research can increase ecological validity because they allow laboratory study of complicated tasks. The ubiquity of computer game-playing means that they are not just generalizable to everyday experience, but are part of it. In the UK, more money is spent on the computer gaming industry than is generated by cinema box-office sales (Poole, 2000, cited in Janz and Martens, 2005). This study demonstrated that Red Bull can significantly improve computer game performance in a sample that differed in the extent and nature of their gaming experience and in their caffeine consumption habits. This heterogeneity of gaming habits adds more generalizability to the study's findings. The sample were unevenly divided in relation to gender (18 of the sample were male and 3 female), however computer gaming is widely considered a male-dominated pass-time, though this is not often documented. But Janz and Martens (2005) did find a male to female ratio of 40:1 when they studied the list of 1,200 visitors to the recent UK LAN event ‘Campzone 2’, so it seems an uneven
gender split should be expected from an opportunity sample from the computer gaming population. Indeed, the male: female ratio of 6:1 in the current study may be surprisingly representative of female gamers for such a small sample.

From an applied perspective, computer gamers now have a reason beyond clever niche marketing to use Red Bull specifically as a performance enhancer in their gaming activities. The specific pattern of cognitive effects through which Red Bull improves computer gaming performance remains unclear, but based on previous caffeine research is likely to involve enhanced reaction times. Study designs involving larger samples and perhaps trying to differentiate between the effects of caffeine alone, and its effects in combination with taurine and glucuronolactone may prove fruitful avenues of further research. Increasing knowledge of the effects of these other ingredients may allow a more informed selection of cognitive tests to identify a more specific pattern of Red Bull’s cognitive effects.
References


