PUBLISHED PROJECT REPORT

TRL Limited

PUBLISHED PROJECT REPORT PPR059

AN EVALUATION OF ENERGY DRINKS CONTAINING GLUCOSE AND CAFFEINE, USING THE TRL DRIVING SIMULATOR

Version: 1.1

By: A.M. Parkes, I. York, S. Burton, T. Luke (TRL)

Prepared for:

Project Record:	**Fatigue and Driving 3**
Client:	**GlaxoSmithKline Consumer Healthcare R&D**

Published Project Reports are written primarily for the Customer rather than for a general audience and are published with the Customer's approval.

	Approvals
Project Manager	**S. Burton**
Quality Reviewed	**A. Parkes**

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive summary

Sleepiness is considered to be a particular problem for drivers. Reported statistics stating the prevalence of fatigue related accidents vary considerably, and it is now accepted that many estimates are too conservative. Horne (1992) suggests that accidents that might have been caused by sleepiness are often classified as inattention, failures to look or see and misjudged speed and distance. Despite probable inaccuracies in the statistics it is clear that driver fatigue is a significant safety concern. Horne and Rayner (2000) estimated that around ten percent of all road accidents could be attributed to sleepiness, and that the figure increases to around twenty percent for all motorway accidents. This problem is only likely to increase as society moves increasingly close to a 24-hour society and with the growing trend towards living further away from work and working longer hours.

Two previous studies (Parkes, Sexton, Burton, Hu, Shaw and Daggy, 2001; Parkes, Burns, Burton, Hu, Shaw, Cotton and Daggy, 2002) have been conducted to determine:

- The extent to which the TRL Driving Simulator can provide a suitable test environment for fatigue and alertness studies
- The range of data available for analysis
- A preliminary indication of the benefits of energy drinks in real world applications

The results of these two studies showed that the energy drinks studied (containing 75mg caffeine and 37.5g carbohydrate) could help sustain driver alertness and reduce the impact of fatigue on driver performance. It was clear that taking such an energy drink in conjunction with stopping the vehicle to have a rest, could be an effective strategy to assist drivers in coping with fatigue.

The impetus for the current study was to take lessons learned about the development of an appropriate methodology for the investigation of fatigue from the previous studies, and apply them to a different formulation of energy drink. In choosing to use a Driving Simulator as the basis for the trials, it was important to recognise that a sufficient level of simulation sophistication was needed to ensure that the driver behaved in a realistic manner, thereby exploring accurately the relationship between fatigue, alertness and the performance on the driving task.

48 experienced drivers aged between 25 and 50 participated in this study. The sample was split evenly by gender. The sample of drivers was randomly selected from the TRL volunteer database and screened for the requirements of this study. The database is a pool of over 1300 drivers representing a cross-section of the driving population of Hampshire, Berkshire and Surrey. Participants were all healthy, of average body build and fitness, with no sleep problems or excessive daytime sleepiness. They were all non-smokers, free of medication and modest consumers of alcohol. They were paid a small amount as compensation for their time and reimbursed for their travelling expenses.

The study employed a double-blind, placebo controlled, repeated measures design. The three conditions were:

1. **Control drink** (330ml, taste matched to energy drinks),
2. **Level 1 energy drink** (330ml, 60g glucose and **25mg caffeine**)
3. **Level 2 energy drink** (330ml, 60g glucose and **40mg caffeine**)

These drinks were formulated in order to taste and appear the same in all conditions, the only difference being the caffeine and glucose dose. The caffeine and food intake of the participants on the day prior to the trial was also controlled.

The drinks were identified by a code only. The participants were not aware of the condition and the experimenters were only aware of the drink code and not its corresponding details. The order of the conditions was counterbalanced. All aspects of the trials were identical except the drink administered to the participant. All participants were tested during the post lunch dip where natural alertness is at a low.

On a visit prior to the main data collection trials, all participants were introduced to the Driving Simulator and given a test drive to allow them to become familiar with the handling of the car and comfortable with the driving environment. All participants were familiarised with the self reporting tiredness forms and the impairment tests:

- adaptive tracking task,
- critical flicker fusion
- choice reaction test.

They were also given a small sample of the drink to taste.

The trial was scheduled after their screening session and familiarisation drive. The trial started off with a practice drive in the Driving Simulator where drivers were given a chance to re-familiarise themselves with the driving task. Participants were then asked to continue with the experiment when they felt comfortable with the Driving Simulator and all other aspects of the trial.

On conclusion of the trial drive participants completed choice reaction, critical flicker frequency and adaptive tracking tests.

Overall the results indicate an improvement in driving performance after drinking the level 2 drink (containing 40 mg caffeine and 60g glucose) compared to the control drink. Lane keeping, reaction time and following performance were all improved significantly by the level 2 energy drink. Some measures also showed a slight improvement with the level 1 drink (containing 25 mg caffeine and 60g glucose).

The magnitude of the improvement appears consistent across several measures and this lends confidence to the conclusion that the level 2 drink can improve some important aspects of driver performance. The level 1 drink also improved several aspects, although its benefits were less and it is therefore unlikely to have a significant practical benefit in the driving situation.

Results summary:

- The **variability of lane position on the curved section of the route was improved in the level 2 condition**. The average improvement in standard deviation was 2.5cm. This means that in 95% of the observations the level 2 driver would be within a band that is 10cm narrower than a control driver (no energy drink).
- **Both the level 1 and level 2 drinks had a small positive effect on the drivers' response to the lead vehicle in the car following task**. The results were significant (at the 95% confidence level). The treatment drinks produced an improvement of 2-3 metres in maintaining the headway with the lead car.
- **There was an effect on reaction time associated with the level 2 drink** (significant at the 95% confidence level) approximately 25 minutes after taking the drink. There was an improvement of approximately 0.1 second in reaction time compared to the placebo. This would result in an extra 3 metres at a speed of 70 mph.
- Lastly, there were **fewer collisions in both treatment conditions than in the control**. Most interestingly, in the level 2 condition there were no crashes in the later sections where we would expect drivers to be most impaired through fatigue. However, the overall number of events was small and did not allow full statistical analysis.
- The post drive impairment tests did not show any significant differences according to condition, though the trend of the results seemed to indicate that scores were slightly higher with the treatment drinks compared to the controls. This is possibly because the tests were taken so long (75 minutes) after the drink that any residual effect was marginal.

The combination of improved lane keeping, reaction time and response to other traffic provides a very promising picture of the potential benefits to road users of consumption of functional energy drinks with caffeine at the relatively low level of 40 mg.

1 Background

A review of existing research literature has been conducted and the findings are presented in **Appendix A**. They include descriptions of types of sleepiness and associated symptoms and performance deficits. The review also includes reference to studies in various countries that have attempted to estimate the size of the contribution of fatigue to traffic accidents. In addition, the potential contribution of caffeine and glucose to combat the onset or extent of fatigue is discussed.

TRL has extensive experience of research into driver behaviour and performance, and has developed methods and tools to produce a rich picture of the effects of any impairment that may be produced by such factors as ageing, illness, and illicit or medical drugs.

Two previous studies have been conducted (Parkes et al 2001, 2002) to determine:

- The extent to which the TRL Driving Simulator can provide a suitable test environment for fatigue and alertness studies
- The range of data available for analysis
- A preliminary indication of the benefits of energy drinks in real world applications

These studies are outlined in **Appendix B**.

The impetus for the current study was to take lessons learned about the development of an appropriate methodology for the investigation of fatigue from the previous research, and apply them to a different formulation of energy drink.

There are obvious safety and ethical considerations associated with performing experiments of this type on real roads, be they public highways or private road networks. For this reason, in this study, *driving simulation* offered the only realistic option. This approach provides a number of additional benefits, including:

- Repeatability and control of experimental protocol
- Detailed and accurate logging of driver behaviour
- Detailed and accurate logging of vehicle control parameters

In choosing to use a Driving Simulator as the basis for the trials, it was important to recognise that a sufficient level of simulation sophistication, and therefore driving realism, was needed to ensure that the driver behaved in a realistic manner, thereby exploring accurately the relationship between fatigue, alertness and the performance on the driving task.

2 Introduction

2.1 The fatigue problem

Sleepiness and fatigue are considered to be largely subjective psychological concepts and as such have proven very difficult to define. A definition given in Brown (1993) is based on the psychological outcomes of fatigue: “A subjectively experienced disinclination to continue performing the task in hand because of perceived reduction in efficiency”.

According to this definition fatigue is dependent on particular task demands. Sleepiness, although related to fatigue is not exactly the same thing, despite the fact that it has been used interchangeably in a number of contexts (e.g. Dinges, 1995). Sleepiness, unlike the above definition of fatigue is not necessarily dependent on the task and relates specifically to the desire to sleep rather than any perceived performance decrement on a given task. This paper will follow the common practice and use the terms “fatigue” and “sleepiness” synonymously to describe the subjective feeling of the imminent need for sleep, or more precisely “difficulty in maintaining alert wakefulness with a tendency to fall asleep” (Eberhart, Hu and Foresman, 2000).

Sleepiness has a number of debilitating effects. These include cognitive and performance deficits as well as abnormal moods. Cognitive performance deficits relate particularly to tasks requiring sustained attention. Creativity, abstract and innovative thinking are impaired when sleepy. Memory also becomes unreliable in sleepy subjects. Mood changes include irritability, negativity and loss of empathy. These impairments can result in problems in the workplace, home, classroom and in particular on the road. The problem is exacerbated by the fact that the magnitude of decrements in performance is not generally related to introspective sleepiness. This limits the extent to which a sleepy individual can compensate for their reduced performance (Mahowald, 2000).

The human body operates according to a number of neurobiological rhythms. The bimodal circadian rhythm governing sleep is governed by the suprachiasmatic nucleus of the hypothalamus. It includes two low points where alertness is naturally low and the desire to sleep is especially salient. These two periods are the early-mid afternoon and the very early morning, typically 4-6am (Horne, 1992). Industrial and work place accidents are most common during these periods as are motor vehicle accidents (Mahowald, 2000). There are several examples of high profile disasters that occurred during the night, for example, Chernobyl nuclear explosion and the grounding of the oil tanker Exxon Valdez (Dinges, 1995). Horne (1992) claims that a driver is 10 times more likely to be involved in an accident if on the road between 4 and 6 am. Other studies have confirmed this conclusion, for example, Akerstedt and Keckland (2001) used data from police records and identified the peak time for motorway accidents as 5am.

Sleepiness is considered to be a particular problem for drivers. Reported statistics stating the prevalence of fatigue related accidents vary considerably, and it is widely accepted that these estimates are too conservative, as there is widespread underreporting. Horne (1992) suggests that accidents that might have been caused by sleepiness are often classified as inattention, failures to look or see and misjudged speed and distance. Appendix A summarises a variety of research projects that have reported statistics on fatigue related incidents. Despite probable inaccuracies in the statistics it is clear that driver fatigue is a significant safety concern. This problem is only likely to increase as society moves increasingly close to a 24-hour society and with the growing trend towards living further away from work and working longer hours.

2.2 Combating the problem

There are a number of countermeasures that drivers employ in order to combat sleepiness while driving. These include opening the window, turning up the radio, taking a walk, and so on. The majority of these measures are ineffective as antidotes to sleepiness. Only ingesting caffeine and sleep were effective (Reyner and Horne, 1998).

2.2.1 Caffeine

Caffeine is a naturally occurring chemical. It is present in many popular drinks. Brewed coffee has the highest caffeine content, approximately 100-150 mg/180ml; instant coffee has 60-80mg/180 ml. Tea has the highest variability in caffeine content with 40-100 mg/180 ml and cola drinks have 17-55 mg/180 ml. Caffeine has numerous effects on human physiology; it stimulates all levels of the CNS (Central Nervous System). Doses of 100-200 mg of orally administered caffeine can produce more rapid and clearer thought flow and increased wakefulness and cortical arousal. It is possible to develop tolerance to the CNS effects of caffeine. At very high doses caffeine can affect the cardiovascular system and result in increased heart rate, force of contraction, cardiac output and heart work. Caffeine may also have a diuretic effect at large dose levels (American Society of Health Systems, 2002).

There have been numerous studies that examine the effect of caffeine on human mood and performance. Johnson-Koslow, Kritz-Silverstein, Barrett-Connor and Morton (2002) examined lifetime coffee consumption in relation to cognitive performance, and found a positive relationship in women only. There was also a relationship between current coffee consumption and two of the cognitive tests. The relationship between coffee intake and cognitive performance has been supported by several other studies. Jarvis (1993) found that this relationship was strongest among older participants. Smit and Rogers (2000) demonstrated that low doses of caffeine, such as those found in a single serving of tea, coffee or cola, can enhance cognitive performance. This effect is robust for both high and low caffeine consumers.

Smit and Rogers (2000) also examined the effect of low dose caffeine on mood. The highest doses of caffeine in the study (100mg) seemed to result in increased tense arousal. Brice and Smith (2002) listed other behavioural effects of caffeine that have been empirically demonstrated; increased alertness, faster reaction times, improved accuracy on choice reaction, improved vigilance and improved tracking accuracy. All of these effects could result in improved driving performance. Increased alertness is of particular interest as it could counteract the negative impact of fatigue on driving.

Caffeine has been investigated as a countermeasure to fatigue in driving. De Valck and Cluydts (2001) administered 300mg of slow release caffeine and measured lane deviation, deviation from the posted speed limit and accident liability as measures of driving performance. The study examined two groups of drivers; sleep deprived and non-sleep deprived. The caffeine counteracted the increased lane drifting and speed deviation evident in the sleep deprived group. Caffeine also improved lane keeping in non-sleep deprived individuals indicating that it is of benefit even in optimal conditions. This study demonstrates the effectiveness of counteracting fatigue-related deficits in drivers. However, this slow release caffeine behaves quite differently to the caffeine a driver would normally consume in a drink if they felt sleepy. Slow release caffeine results in a smooth prolonged effect as opposed to a sudden burst of wakefulness. This may be more beneficial than normal caffeine. However, it is not a realistic study of the effects of caffeine consumption in drivers. In addition, this study used a much higher dose that would be expected in a single serving of a caffeine rich drink.

2.2.2 Glucose

Glucose is the principle source of fuel for the brain, on this basis it has been hypothesised that glucose may also enhance cognitive functioning. Benton and Owen (1993a) examined the relationship between glucose intake and memory. There was a correlation between blood glucose and the number of words recalled. This relationship was not dependent on the participants' initial blood glucose level; glucose appeared to enhance memory in all cases where blood glucose levels were increasing. Glucose did not, however, have a global effect on memory, as there was no relationship between glucose levels and spatial memory or the recall of a story. The effect of glucose on memory has been confirmed in a number of other studies in both young and elderly (e.g. Benton, Owen and Parker, 1994; Hall, Gonder-Frederick, Chewning, Silviera, and Gold, 1989)

Benton et al (1994) also examined the effect of glucose on attention tasks. An association was found between blood glucose levels and two classic attention tasks; the Stroop task, and the RIPT (Rapid Information Processing Task). In general, in participants with increasing blood glucose performance were faster on both of these attention tasks. Having increasing blood glucose leaves a reserve of fuel for the brain to utilise in demanding cognitive situations and therefore allows the brain to maintain maximum performance.

Owen and Benton (1994) examined the impact of glucose on decision reaction times. Glucose was beneficial to performance on the most demanding tasks but had no effect for simple reaction times, movement and inspection times. This is likely related to the fact that blood glucose indicates the availability of glucose to the brain. When the task is not demanding, glucose is not rapidly spent and therefore the reserve of glucose has little relevance.

Lastly, raised blood glucose is associated with some changes in mood. Benton and Owen (1993b) found that higher levels of blood glucose correlated with higher reported energy and less tension. The beneficial effects of raised blood glucose levels on memory and attention, and even the positive impact on mood are relevant to driving behaviour. It is possible that these benefits may combine to counteract some of the debilitating effects of fatigue on drivers. The effects of glucose on driver behaviour have not been extensively studied. However, the effects of several functional energy drinks, which usually contain a combination of both glucose and caffeine, have been studied in relation to driver performance.

2.2.3 Functional energy drinks

Several studies have examined the effects of a functional energy drink “Red Bull” on driver performance. This drink contains 80mg/250ml caffeine, 11.3g/100ml of glucose and 4g/100ml of taurine as well as glucuronolactone and a vitamin B complex. Horne and Reyner (2001) examined lane keeping performance and reaction times of sleep deprived subjects (sleep limited to 5h) after the administration of 500ml of the energy drink (i.e. 160mg of caffeine). The energy drink counteracted the effects of fatigue and both lane keeping and reaction time in a low-fidelity part-task driving simulator were improved.

Reyner and Horne (2002) repeated this study using 250-ml dose of the energy drink and measured lane drifting, subjective sleepiness and electroencephalogram (EEG). The energy drink was beneficial in reducing lane drifting and subjective sleepiness.

Parkes et al (2001) evaluated the effects of an energy drink (Solstice®, GlaxoSmithKline, UK) on driver’s performance after a normal night’s sleep. Performance was evaluated during the post lunch dip and during the evening. The drink provided 75mg of Caffeine and 37.5 g of glucose. This formulation was compared to a placebo which was matched for colour, taste and temperature. Both drinks were administered in a single 250ml dose.

The results revealed several benefits of the energy drink compared to the placebo. Self-report scales of sleepiness indicated that both drinks had an alerting effect, however, the level and duration of the alerting effect was greater for the energy drink than for the placebo. The energy drink also improved performance on an adaptive tracking task and this improvement in hand-eye coordination was reflected in better lane keeping performance during a simulated driving task. Finally, in the placebo condition the drivers tended to drive faster in traffic than in the energy drink condition. The energy drink did not produce any benefits on other performance measures such as speed variability and situation awareness.

A second study of the effect of drink formula was conducted by Parkes et al (2002). This used a similar procedure to the initial study. The same energy drink was compared to a matched placebo and to water. Performance on a simulated driving task was measured during the post-lunch dip after a standardised lunch.

The energy drink resulted in significant improvement in driving performance, demonstrated by less varied speed, better lane keeping, fewer critical incidents and faster reaction times when compared to the placebo. In addition, the energy drink improved adaptive tracking performance, self-report ratings of sleepiness and visible signs of fatigue.

In summary, it has been shown that fatigue is slowly becoming recognised as a major threat to road safety. Statistics vary wildly as to the exact incidence of “fall asleep” accidents, though this is likely due to underreporting or misclassification of this type of accident. To date, very few countermeasures have been shown to be effective in reducing driver sleepiness, other than the ingestion of caffeine and sleep. Caffeine has been shown to increase alertness, improve cognition, vigilance and tracking. These are all beneficial to the sleepy driver. However, caffeine may also result in tense arousal at the highest doses. Glucose has also been shown to improve cognition and memory and result in a relief on tension and greater reported energy. Caffeine and glucose can both result in beneficial effects for a sleepy driver.

Functional energy drinks usually contain caffeine and glucose in addition to other ingredients. Several studies have looked at energy drinks as a counter measure to sleepiness and found them to have an even greater enhancing effect that caffeine alone. These studies have been conducted both on partially sleep-deprived individuals and after normal sleep, and have demonstrated that functional energy drinks can be effective in combating the impairments caused by both sleep deprivation and the natural dips in alertness that are an inevitable consequence of the human circadian rhythm.

This background provides clear evidence of the benefit of drinks containing relatively high levels of caffeine. The impetus for the current study was to explore the potential benefits of energy drink formulations containing lower levels of caffeine in combination with glucose and other active ingredients.

3 Method

3.1 Participants

48 experienced drivers aged between 25 and 50 (M = 35.4, SD = 8.2) participated in this study. The sample was split evenly by gender. The sample of drivers was selected at random from the TRL volunteer database and screened for the requirements of this study. The database is a pool of over 1300 drivers representing a cross-section of the driving population of Hampshire, Berkshire and Surrey. Participants were all healthy, of average body build and fitness, with no sleep problems or excessive daytime sleepiness. They were all non-smokers, free of medication and modest consumers of alcohol.

3.2 Design

The study employed a double-blind, placebo-controlled, repeated-measures design. The three conditions were:

1. **Control drink** (330ml, colour and flavour matched to energy drinks),
2. **Level 1 energy drink** (330ml, 60g glucose and **25mg caffeine**)
3. **Level 2 energy drink** (330ml, 60g glucose and **40mg caffeine**)

These drinks were formulated in order to taste and appear the same in all conditions; the only difference being the caffeine and glucose dose. The caffeine and food intake of the participants on the day prior to the trial was also controlled.

The drinks were identified by a code only. The participants were not aware of the condition and the experimenters were only aware of the drink code and not its corresponding details. The order of the conditions was counterbalanced according to the pattern defined in **Appendix E.** All aspects of the trials were identical except the drink administered to the participant. All participants were tested during the post lunch dip where natural alertness is at a low (Horne, Brass and Pettit 1980).

3.3 Procedure

Prior to the main trials all participants were invited to the laboratory for a familiarisation session. During this session participants were familiarised with all aspects of the procedure. A variety of background information was collected: driving history; health; normal sleeping patterns and daily caffeine intake. The participants' normal patterns of alertness were assessed using the morningness/eveningness questionnaire (Horne and Ostberg 1976). A copy of this questionnaire is provided in **Appendix C**.

The main trial started with a practice drive in the Driving Simulator. The standardised instructions and the schedule of this practice drive are provided in **Appendix F**. Sleepiness was assessed immediately before and after the practice drive using the Karolinska Sleepiness Scale (KSS). An example of the KSS is included in **Appendix G.**

Prior to the experimental drive the participants were given 330ml of one of the drinks and instructed to drink it as quickly as was comfortable. They were also provided with standardised written instructions relating to the car-following task part of the drive and given the opportunity to ask questions about all other tasks. Sleepiness was assessed by the KSS immediately after the participant finished the drink.

Participants then commenced the trial drive. Before moving away a red block was visible on the simulated motorway scene. Participants were instructed that a similar block would appear at various occasions during their drive and that they should react to this by flashing their headlights as soon as they saw it. The experimenter used an intercom system at pre-specified points on the route to question the participant about their level of sleepiness. A total of five KSS responses were collected during the trial drive. All participant responses were verbally clarified to ensure reliability. A complete description of all instructions and questions given on the route is provided in **Appendix F.**

On conclusion of the trial drive, participants completed three impairment tests: choice reaction; critical flicker frequency and adaptive tracking. Sleepiness was assessed immediately after these tests using the KSS.

3.4 Equipment

Figure 1– TRL Driving Simulator

The TRL Driving Simulator is one of the most sophisticated and realistic Driving Simulators available in Europe. At the time of the study it consisted of a medium size saloon car surrounded by 3 X 4 meter projection screens giving 210 degree horizontal front vision and 60 degree horizontal rear vision, enabling the normal use of vehicle mirrors. The car body shell was mounted on hydraulic rams that supply motion to simulate the heave, pitch and roll experienced in normal braking, accelerating and cornering. The Driving Simulator provided realistic forces experienced by the driver through the steering wheel, pedals and gear lever. The provision of car engine noise, external road noise, and the sounds of passing traffic further enhance the realism of the driving experience. The simulation employs a validated vehicle model ensuring that the acceleration, braking and manoeuvring characteristics of the driven vehicle are accurate representations of the equivalent real world vehicle.

A CCD colour video camera (PULNiX TMC-X) was mounted on the cowl above the instrument cluster in a position to capture a clear view of the drivers' eye movements. The camera images were recorded on a video (PANASONIC AG 7350) mixed together with the forward view of the simulated road scene and the speedometer.

3.5 Route and Traffic Scenarios

Participants drove a 131-km simulated motorway. The route was designed in four parts: normal in-traffic drive; curved road section; car following section and in-traffic section. Each section included a reaction event.

In an attempt to induce boredom and initiate driver fatigue the driving scene was deliberately bland and the participants were not allowed use of the in-car music system.

3.5.1 Normal in-traffic drive

The route started with a section of motorway in moderate traffic conditions where participants were instructed to drive as they would normally in this situation. The motorway had three lanes and the speed limit was 70 mph (113 km/h), the standard speed for motorways in the UK. The traffic was programmed to vary its speeds in relation to the subject's vehicle and could overtake or be overtaken depending on how the subject drove. This motorway section continued for 60 km and took approximately 30 minutes to complete.

Figure 2 - Example motorway traffic scene

3.5.2 Curved road section

The normal motorway section was followed by a section of two-lane curved road. This was used to measure the driver's ability to control the vehicle on a more demanding type of road. The curves had a total length of 19 km, this took approximately 10 minutes to complete. The loops were modelled on the TRL research track and each had a continually changing radius. Drivers were instructed to maintain a speed of 60 mph (96.6 km/h).

Figure 3– Example curved section of route scene

3.5.3 Car following section

At the end of the curved section drivers were informed that they were rejoining the motorway. The only traffic on this section of motorway was one vehicle that the participants were instructed to follow. Participants were asked to maintain a distance of two chevrons (60m). Chevrons were marked on the road at the beginning of the section to allow the participant to select the following distance.

The chevrons then disappeared for a short period to allow the participant to practice maintaining the following distance. Finally the chevrons reappeared to allow the driver to check the distance before disappearing for the rest of the following section. The total length of the following section, including distance setting and practice was 23km. The duration of this section was approximately 15 minutes. The lead vehicle oscillated its speed gently between 50 and 70 mph (80 & 113 km/h) throughout the following section.

Figure 4 – Example car following scene

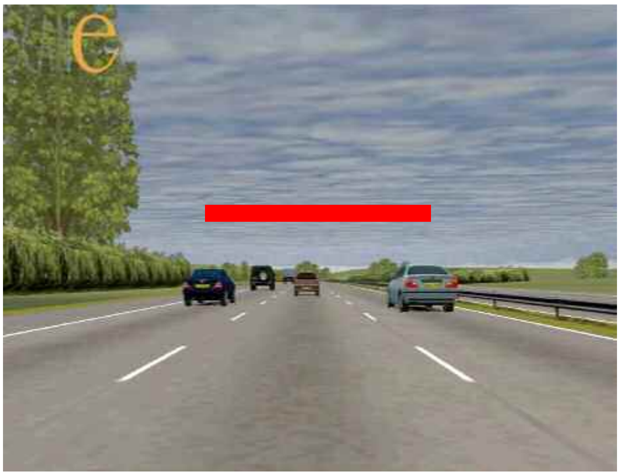
3.5.4 In-traffic section

A further motorway section with three lanes and moderate traffic was the final component of the route. As before, the participant was instructed to drive normally in this section. This final section was 25km in length and took approximately 15 minutes to complete.

3.5.5 Reaction event

There were four reaction events on the route. The drivers were instructed to flash their headlights in response to the large red bar that appeared at the centre of the forward road scene.

Figure 5 – Example of reaction event



3.6 Dependent Variables

A selection of dependent measures was used to capture the impact of the different drink formulations on performance and feelings of fatigue. Some of these measures only apply to certain portions of the route, where this is the case it is stated in Table 1. Some of the measures were calculated separately for different sections of the route.

Table 1 – Dependent variables

Dependent Variables	Measures	Description/ comment
Driver behaviour measures		
Speed	Mean Standard deviation (SD) Acceleration and deceleration rates	Not calculated for car following For car following only
Headway/Time Headway	Mean SD Percentage of time headways < 0.7s Speed of adaptation	Not calculated for car following Speed of reaction to changes in the lead car - car following task only
Lane choice	Percentage time	Only considered on motorway sections
Lateral deviation	SD of movement in the lane (cm)	Movement within the lane – all sections of route
Critical incidents	Count	Number of crashes
Reaction time	Time	Reaction to specified reaction events only
Impairment test measures		
Choice reaction time (CRT)	Reaction times	
Critical flicker fusion (CFF)	Threshold in cycles per second	
Adaptive tracking (AT)	Mean tracking speed	
Physiological measures		
Yawning	Yawn count	
Eye movement	Blink frequency/count Eye closure frequency Percentage of eye closure	Number of blinks per minute/total number of blinks Number of eye closures (> 80% and covering pupil)
Subjective measures		
Sleepiness	Participant's rating of sleepiness	Measured using Karolinska Sleepiness Scale (KSS)

3.7 Physical Observations

The eye blink data collection was undertaken by one person, who analysed only one participant per day. The task of counting eye-blinks, yawns and closures is somewhat subjective, and having only one person perform all the counts avoided subjective variation between counts.

The data collection involved watching the video recording of the participant's face taken whilst they were driving. During the video playback click-counters were used to count the number of blinks, yawns and eye closures. The video was then replayed and a stopwatch used to time how long the subject had their eyes closed.

Four 5km sections of the drive were analysed:

- Section 1: Long open motorway - 10km-15km
- Section 2: Cornering Task - 64km-69km
- Section 3: Following Task - 85km-90km
- Section 4: Long open motorway - 124km-129km

These sections give an overview of the complete drive as they include behaviour during each of the tasks, as well as behaviour at the beginning of the drive and shortly before the end, which should be when they are at their most alert and most sleepy respectively.

In each section, data was collected for the 5km before the KSS score was requested. Data collection was during the time when external stimuli (e.g. KSS, Reaction Test) could not affect the measure.

3.7.1 Blinks and Yawns

Blinks and yawns were counted for each 5km section. As subjects drove the 5km at different speeds the times at the beginning and end of the section were recorded which enabled a blink rate and yawn rate to be calculated.

3.7.2 Eye Closures

An eye closure was classed as one when the eye was at least 80% closed for more than 0.5 seconds. The amount of time the participants had their eyes closed was timed on a stopwatch (to the nearest half-second).

3.7.3 Other Events

Other unusual events were noted; such as: the subject rubbing their eye through tiredness; slapping their faces or jerking their head in an effort to keep themselves awake; falling low into their seat or leaning their head on their arm or the window or if the subject actually fell asleep.

When subjects did become particularly tired some moved their head out of the view of the camera. In these instances the amount of time when both of their eyes were out of view of the camera was timed so this could be deducted from the section time used to calculate the blink rate. Generally, there were very few occasions when this occurred and the duration of time when both eyes were obscured was small.

3.8 Questionnaires and Scales

3.8.1 Morningness-eveningness Questionnaire (Horne and Ostberg, 1976)

There are considerable individual differences in human circadian rhythms. Some people experience their peak of alertness in the evening where others experience greater alertness in the morning. The morningness-eveningness questionnaire measures the magnitude of an individual's tendency to feel most alert at one particular time of day. The questionnaire consists of a mixture of multiple choice and scaled questions relating to subjective feelings of alertness and wellbeing at different times of the day. This questionnaire was used as part of the screening process. Participants with a strong tendency to either morningness or eveningness were excluded from the study. A full copy of the questionnaire is available in **Appendix C.**

3.8.2 Karolinska Sleepiness Scale

The Karolinska sleepiness scale (**Appendix G)** is used to assess an individual's level of alertness at a particular moment. It can therefore be given periodically to assess how subjective levels of alertness change over time. It consists of a simple 9-point scale that ranges from 1 - "Extremely alert" to 9 - "Extremely sleepy, fighting sleep." The participant identifies the point verbally on the scale that best describes the way that they feel at that particular moment.

3.9 Analysis

The data were analysed to determine the effect of the treatment drinks on driver performance and subjective driver fatigue. The data were screened for anomalies (e.g. implausible values) and violations of parametric assumptions. This was followed by the inferential analyses. The main analysis was a repeated measures analysis of variance (ANOVA). Comparisons in driving performance, subjective sleepiness and physical observations were made for the same section of the route. For example, the mean standard deviation of lane keeping for curves with the control drink was compared to the mean for those same curves during the level 1 and level 2 conditions. Changes in performance over time were also examined.

3.9.1 Speed

Speed and speed variability are measures of driver behaviour and performance. Increased speed variability is thought to indicate that a driver is unable to monitor and maintain a constant speed.

3.9.2 Distance headway and timed headways

Distance headway is the distance between the driven simulator vehicle and a lead vehicle in the traffic scene, in metres. Smaller headways are considered to be more dangerous as the following driver has less time to react to the behaviour of the lead vehicle. In Section 3 the participant was instructed to follow the lead vehicle at a set distance of approximately 60 metres.

Timed headway is a measure of the minimum approach time between the subject vehicle and lead vehicle measured in seconds: i.e. the time it takes the subject vehicle to reach the location of the lead vehicle at a given instant in time. This measure was most closely examined during the 10 minutes segment of car following on the motorway.

Variability in distance headway and timed headway are measures of driving performance. When instructed to maintain a fixed distance, any fluctuations in that distance reflect a poorer ability to perceive and compensate for fluctuations in the gap.

The critical difference between safe and unsafe time headways has been set to be 0.7 seconds. Anything less than 0.7 seconds is considered inappropriate because drivers are unable to react to a change in the lead vehicle's speed.

3.9.3 Speed adaptation

In the third section of the route the drivers were instructed to maintain a constant distance between themselves and the car in front. During the section the lead car decelerated and accelerated a number of times and the ability of the driver to adapt speed to keep a constant distance is a measure of driving performance. That is, a larger minimum distance when the lead car is decelerating, and a smaller maximum when it is accelerating, indicates higher performance.

3.9.4 Maximum accelerations and deceleration in section 3 (car following)

The ability of the driver to gradually adapt speed to keep a constant distance is another measure of driving performance. That is, a smaller maximum deceleration when the lead car is decelerating, and a smaller maximum acceleration when it is accelerating, indicates higher performance.

3.9.5 Critical incidents

A critical incident in this research is defined as any event where the subject's vehicle contacts another vehicle or leaves the road. This is a direct measure of safety. It should be noted that in this experiment there were no instances of vehicles leaving the road, all collisions were with other vehicles and were promoted by the special circumstances of the experimental scenarios.

3.9.6 Simple reaction time

Drivers were required to react to the appearance of a target object (red block) by flashing their headlights. The blocks appeared once in each of the four sections of the drive. The time was measured from when the target appeared to when they flashed their headlights. The faster the driver reacts, the more prepared they would be to respond to sudden events in the road traffic environment.

3.9.7 Post drive impairment tests

After completing the drive, subjects took part in three computer-based tests to assess their degree of awareness. These were:

- Adaptive Tracking (AT)
- Choice Reaction Task (CRT)
- Critical Flicker Frequency (CFF)

During adaptive tracking the subject had to keep a cursor following a target on a PC screen by using a joystick. Performance was measured as the mean tracking speed. The speed of the task increased adaptively if the subject was tracking well. Therefore, a higher value represents better performance and is associated with a more alert subject.

The Choice Reaction Task uses multiple stimuli and response possibilities, thereby placing a greater information-processing load on subjects than simple reaction time. CRT is relevant to driving in that many aspects of the driving task require choice reactions, for example, responding to a traffic light. In this study a dedicated display device was used that required the participant to move a finger on the preferred hand from a resting point to a target. The target could be in one of six possible positions, each equidistant from the resting point. On each occasion between one and six target possibilities were presented. There were 24 presentations per trial.

Critical Flicker Frequency is a measure of visual fatigue. Subjects indicated both when a flashing LED increased in rapidity to the point where it became steady, and conversely, when a steady LED slowed and began to flash. A traditional method of limits approach was taken. The threshold for visual flicker was expressed in cycles per second. A higher value represents a better score and is associated with lower visual fatigue.

4 Results

4.1 Participants' subjective sleepiness

Subjects gave an indication of their subjective fatigue using the KSS on nine occasions during each of their visits. Scores range from 1 (extremely alert) to 9 (extremely sleepy). There were two pre-dose values and seven post-dose values of the KSS. The approximate times that these assessments took place are summarised below.

Table 2 - Times of KSS scores

KSS Number	Task being or just performed	Time from drink (mins)
1	Start	-15
2	Baseline drive	-5
3	Drink	0
4	Open motorway drive in normal traffic	15
5	Open motorway drive in normal traffic	25
6	Curves and constant 60mph speed	35
7	Car following	45
8	Open motorway drive in moderate traffic	65
9	After all computer based impairment tests	80

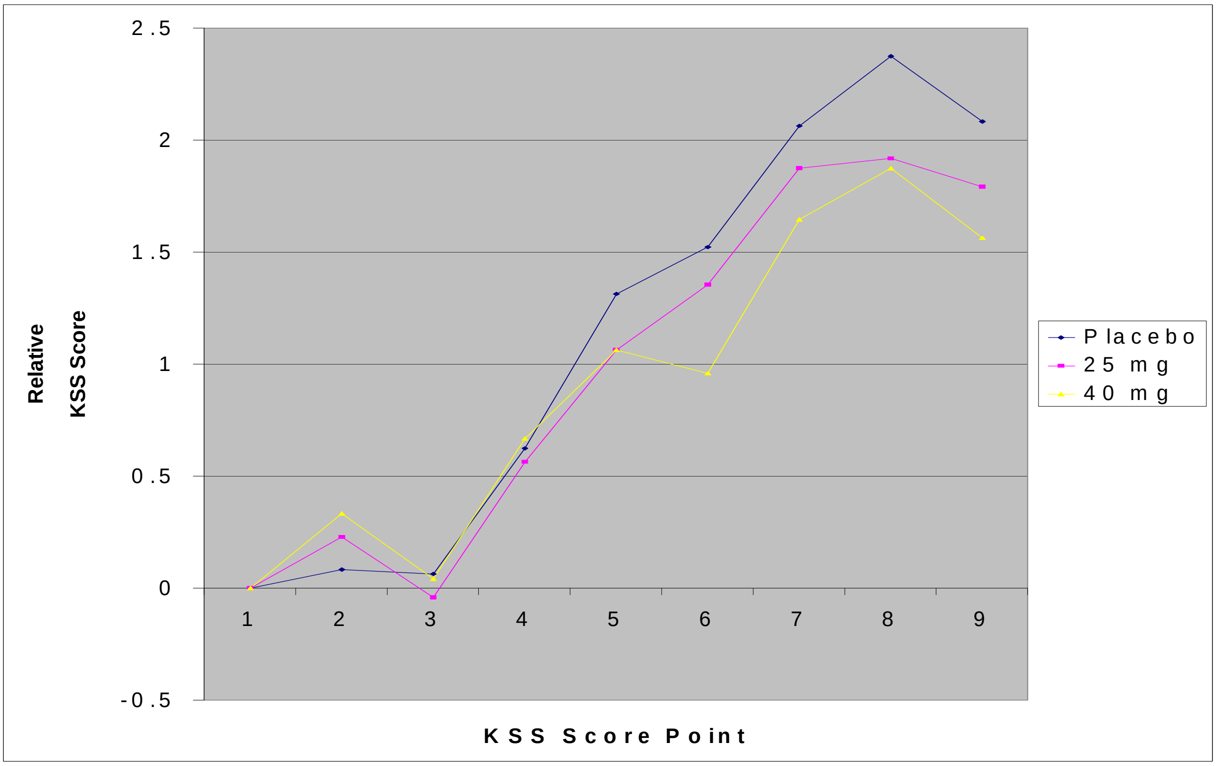
Subjective ratings of fatigue provide insight into the participants' perceived condition. This measure is sensitive to early symptoms of fatigue, before any signs of performance decrement can be detected.

A person's first scores on the three individual runs (different days) should be consistent, as drivers were instructed to follow similar eating, drinking and sleeping patterns on the night before each of the drives. However, variations were found. To compensate for this variation, the relative scores (to the first) during each run were calculated. This measure therefore estimates the degree to which the drivers became more tired during the course of the experiment, see

Figure 6.

The graph shows clearly that neither formulation has a strong effect up to 25 to 35 minutes after the drivers took the drink. After this point, effects of around 0.5 on the KSS scale were reported on average.

Figure 6 – Average relative KSS Scores



Paired t-tests on the KSS scores in the latter part of the experiment indicate that the drivers considered themselves to be significantly less sleepy (more aware) when asked to judge themselves at points approximately 35 and 65 minutes after taking the 40mg formulation, than with the placebo ($p < 0.05$).

There is an indication that the 40mg formulation has an effect on the KSS score at point 6 ($p < 0.05$), approximately 35 minutes after taking the formulation. These results are consistent with those of Parkes et al (2002) which investigated the effects of a drink formulation containing 75mg caffeine and showed yet higher effects on subjective sleepiness.

4.2 Driving measures

4.2.1 Speed

In this study, drivers correctly maintained an average speed of 60mph in section 2 (the curves), and the variation of their speed within this section was relatively small. All differences in speed and its standard deviation on these sections were small and non significant.

4.2.2 Distance headway

Analysis of distance headway data was performed on section 3 where the Driving Simulator car was following a lead car. It was also performed on both of the general motorway driving sections (Sections 1 and 4).

The formulations had no observed effect on the average distance headway that drivers' maintained between their vehicle and the one in front, for any section of the route.

4.2.2.1 Section 1 – Motorway driving

No trends could be found in any of these measures for data recorded in Section 1 of the Driving Simulator experiment.

4.2.2.2 Section 3 – Car following

Analysis of section 3 showed that the main effect of drink formulation on SD of distance headway approached significance {$F(2) = 2.806$, $p = 0.06$}. In this section an average driver was found to permit their distance headway to vary by approximately a further three metres with the placebo than with the 40mg formulation.

Paired t-tests with an HSD correction on the SD of distance headway in section 3 found that the drivers varied their headway significantly less with the 40mg formulation than with the placebo ($p < 0.05$).

The average minimum distance headways show the same pattern as the standard deviation of headway, with a smaller minimum headway associated with the placebo than with the other formulations. However, these differences were not statistically significant.

4.2.2.3 Section 4 – Motorway driving

Distance headways in Section 4 were more variable due to the traffic conditions on the road, with the drivers not only maintaining safe distances, but also accelerating and passing other vehicles. The significant effect of the treatments detected was in the SD of the headways within the second half of this section. An average driver varied their headway by 1.9 metres less ($p < 0.05$) with the 40mg caffeine formulation.

4.2.3 Short timed headway

No significant differences were found in the time that drivers were close (< 0.7 seconds) to vehicles in front between the formulations.

4.2.4 Speed adaptation

No significant differences were found in the minimum distance between the vehicles in Section 3 when the lead car decelerated, or the maximum distance between them when it accelerated. However, on average the distance headways were two to three metres improved in reacting to the lead car changes on drives after drinking the 25mg and 40mg formulations ($p < 0.05$). The average minimum and maximum distances with the placebo were 38.9 and 153.2 metres respectively, whilst with the 25mg and 40mg formulations the minimum ranged between 40.8 and 41.1 metres, and the maximum ranged between 149.7 and 150.5 metres.

4.2.5 Maximum accelerations and deceleration in section 3 (car following)

No differences between the average driver's acceleration rate when the lead car was accelerating, and the deceleration rate when the lead car was decelerating were found.

4.2.6 Lane choice

Fatigue could have an effect on driving style. That is, drivers' approach to driving could be to stay in the inside lane and reduce workload, or use outer lanes to travel faster and complete the journey quicker. However, there were no significant effects of formulation on lane choice on any section of the route.

4.2.7 Lane Position

As with the other vehicle control measures, fatigue reduces the driver's ability to monitor performance. The standard deviation of lane position is sensitive to this change because it increases as the driver finds it more difficult to monitor and maintain their position within the lane.

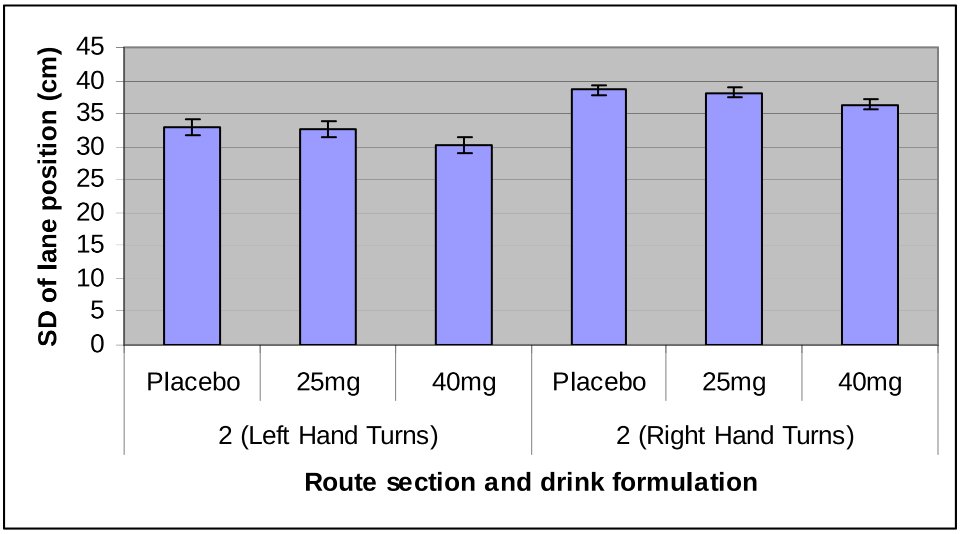
4.2.7.1 Sections 1, 3 and 4

The standard deviation of lateral deviation varies by only up to 0.6cm on average between the formulations on Sections 1, 3 and 4. No differences between formulations in these sections were significant.

4.2.7.2 Section 2 - Curves

There is an indication that the 40mg formulation improves the standard deviation of lane position in the curve tracking task. The improvement is of the order of 2.5cm on average (see Figure 7).

Figure 7 – SD of lane position on curves (section 2)



Larger changes in lateral deviation of up to 2.7cm are found in Section 2, the curve following section. The ANOVA for left hand curves indicates that the formulation has an effect at the $p < 0.10$ level. Further pairwise comparison implies that the 40mg formulation has an effect ($p < 0.05$) when compared to the placebo, but does not show a significant difference to the 25mg formulation.

Table 3 - Pairwise comparisons of SD of Lateral Deviation for left turn in Section 2

(I) Drink Level Taken	(J) Drink Level Taken	Mean Difference (I-J)	Std. Error	Sig.(a)
Placebo	25mg	0.5	1.1	.613
	40mg	2.3	1.1	.029
25mg	40mg	1.8	1.1	.092

4.2.8 Critical Incidents

More crashes appear to have occurred with the drives made after drinking the placebo, than with either of the other formulations

However, the total number of crashes (control placebo = 10, 40mg = 4, and 25mg = 4) precludes any detailed non-parametric statistical analysis.

4.2.9 Simple Reaction Time

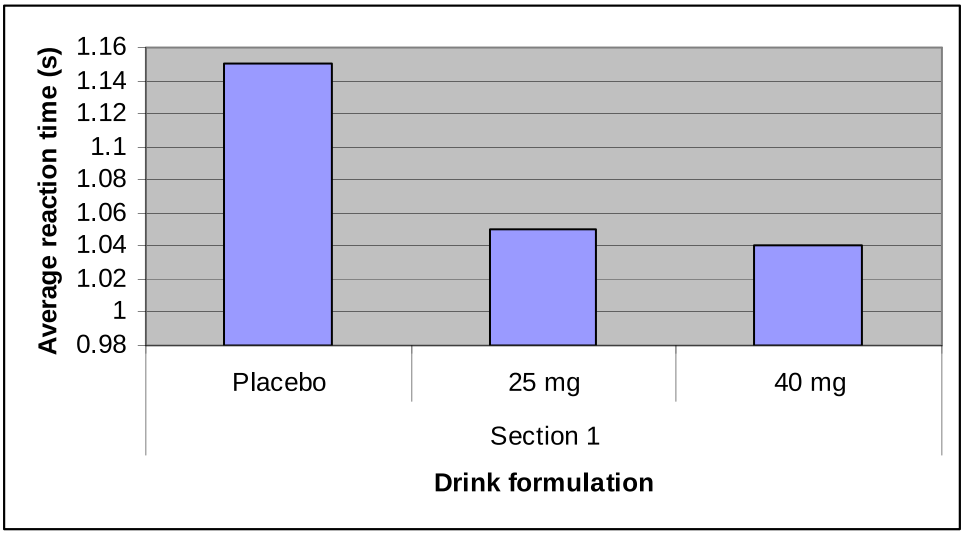
Drink formulation had a small but significant effect on reaction time observed 20 to 25 minutes into the drive. The 40mg drink reduced reaction times by approximately 0.1 seconds, equivalent to approximately travelling three metres at 70 mph.

4.2.10 Average Reaction Times

ANOVA analysis shows that the differences in reaction time by formulation are not significant in Sections 2, 3 and 4.

Formulation had a significant effect on reaction time in Section 1 {F(2) = 3.108, $p < 0.05$}. Independent samples t-tests indicated that the average reaction time was significantly less with the 40mg formulation than with the placebo {t(90) = 1.675, $p < 0.05$}. This reaction event was approximately 44.5km into the drive, and therefore 20 to 25 minutes after drinking the formulation (see Figure 8).

Figure 8 – Average reaction time according to formulation in section 1



The average difference in reaction times between the placebo and the 40mg formulation is 0.1 seconds. At motorway speeds of 70mph, this saving would equate to around three meters travelled.

4.3 Post drive impairment tests

No significant differences in any of these measures were found between the drives after drinking the different formulations. However, all trends were in the expected direction (see

Table 4).

Table 4 - Means and Standard Deviations in Post Drive Tests

Measure	**ANOVA** **Significance (p)**	**Formulation**	**Mean**	**Std. Error**
Adaptive Tracking	0.35	Placebo	17.358	.169
		25mg	17.690	.169
		40mg	17.621	.169
Reaction Time	0.41	Placebo	443.382	5.118
		25mg	434.000	5.118
		40mg	436.770	5.205
Critical Flicker Frequency	0.67	Placebo	30.005	.320
		25mg	30.428	.325
		40mg	30.314	.325

4.4 Physical observations

4.4.1 Number of yawns

Results were not significant

4.4.2 Blink Rates

With fatigue, there tends to be an increase in the frequency of blinking. Blinking is defined as fast eyelid closures lasting less than 0.5 seconds. The number of eye blinks was counted over four 5-minute periods, one in each section of the simulator drive.

Less eye blinks were observed in the early sections of the drive, particularly Section 2, where drivers were required to follow a curved section of road at 60mph (see

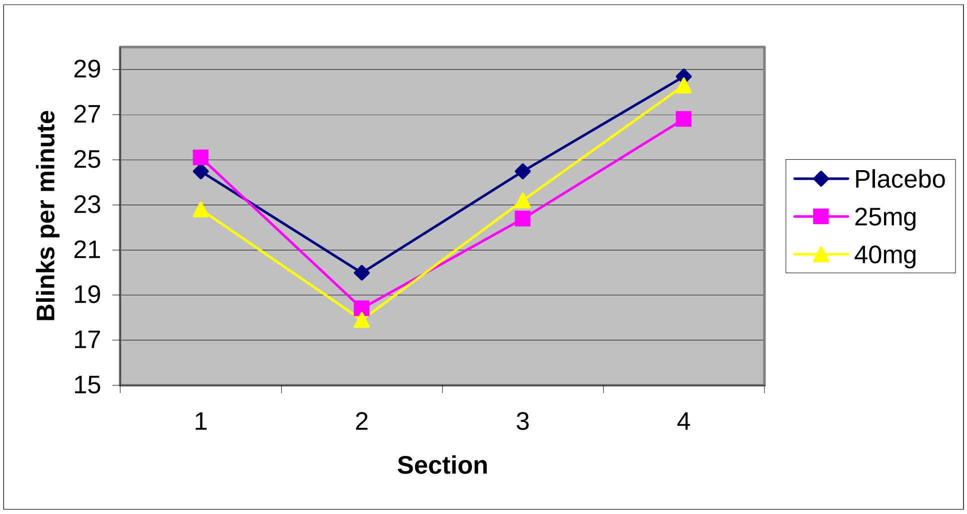
Table 5).

Table 5 - Effect of formulation on blink rate

Section	ANOVA Significance (p)	Formulation	Blinks per minute
1	0.08	Placebo	24.5
		25mg	25.1
		40mg	22.8
2	0.05	Placebo	20.0
		25mg	18.4
		40mg	17.9
3	0.11	Placebo	24.5
		25mg	22.4
		40mg	23.2
4	0.53	Placebo	28.7
		25mg	26.8
		40mg	28.3

The ANOVA post-hoc tests indicate that there is a difference between blink rates with the 40mg formulation and the placebo in the first section. The largest difference is in Section 2, where blink rates generally fall. The blink rate with the 40mg formulation is significantly different to the placebo ($p < 0.05$).

Figure 9 - Blinks per Minute



Blink rates begin to increase in Section 3. These differences do not reach significance.

4.4.3 *Eye Closures*

Slow eyelid closures, or near closures (> 80% and covering pupil), lasting over 0.5 seconds are a further measure, and increase with the near proximity to sleep. The duration of the eyelid closure was recorded in seconds, and each instance of long closure was counted.

The amount of time drivers' eyes were closed did not vary significantly with the drink formulation.

4.4.4 Number of other events

There are other overt behaviours that can be indicative of fatigue, boredom, unrest or the strategies for trying to cope with these states. Such activities include sighing, face rubbing, body shifts and scratching. The occurrence of these behaviours was counted in the video analysis. However, the number of these events that were observed during the experiment was small, and insufficient for detailed analysis.

5 Conclusions

The results indicate an improvement in driving performance after drinking the level 2 drink (40mg caffeine) compared to the control placebo drink.

Lane keeping, reaction time and following performance were all improved by the level 2 drink containing 40mg of caffeine. Some measures also showed a slight improvement with the level 1 drink (25 mg caffeine).

The improvement appears consistent across several measures and this lends confidence to the conclusion that the level 2 drink can improve aspects of driver performance. The level 1 drink also improved several aspects, although its benefits were less and it is therefore unlikely to have any substantial benefit in reducing driving related fatigue.

To summarise:

- The variability of lane position on the curved section of the route was improved by the level 2 drink containing 40mg of caffeine. The average improvement in standard deviation (measure of variability) was 2.5cm. This means that in 95% of the observations the level 2 driver would be within a band that is 10cm narrower than a control driver.
- Both the level 1 and level 2 drinks had a small positive effect on the drivers' response to the lead vehicle in the following task. The results were significant (at the 95% confidence level). The treatment drinks produced an improvement of 2-3 metres in maintaining the headway with the lead car.
- In the level 2 conditions drivers had less variability in their following distance. This equates to an improvement of approximately 3 metres of variation in the headway. The average minimum headway was also smaller in the level 2 condition indicating better maintenance of a safe distance.
- There was an effect on reaction time associated with the level 2 drink (significant at the 95% confidence level), approximately 25 minutes after taking the drink. It appears that there may have been an improvement of approximately 0.1 second in reaction time. This would result in an extra 3 metres at a speed of 70 mph.
- Lastly, there were fewer collisions in the treatment conditions than in the control. Most interestingly, in the level 2 condition there were no crashes in the later sections where we would expect drivers to be most impaired through fatigue. However, the overall number of events was so small that it does not allow proper statistical analysis.
- The post drive impairment tests did not show any differences according to condition. However, the trend of the results seemed to indicate that scores were very slightly better with the treatment drinks compared to the controls. The lack of strong results on these PC based impairment tests is possibly because they were taken around 75 minutes after the drink and any effect would be marginal.

It should be noted that participants were not sleep deprived before the trials in this study, and as such, any reviving effects of the drinks are likely to be conservative.

The two functional energy drinks used in this study used caffeine concentrations lower than would be expected in a single cup of instant coffee, and far less than that of typical brewed coffee. Nevertheless the formulation with 40mg of caffeine and 60g of glucose within a 330ml serving promoted a level of activation that could be observed in realistic driving situations. The magnitude of the changes seen is statistically significant, and the pattern is consistent and congruent with expectations based on research findings in other application domains.

6 References

Akerstedt, T. and Kechland, G. (2001). Age, gender and early morning highway accidents, *Journal of Sleep Research, 10,* 105-110

American Society of Health Systems (2002). *AHFS Drug Information*. American Society of Health Systems: Bethseda

Benton, D. and Owen D.S. (1993a). Blood Glucose and Human Memory. *Psychopharmacology, 113,* 83-88

Benton, D. and Owen, D.S. (1993b). Is raised glucose associated with the relief of tension? *Journal of Psychosomatic Research, 37(7),* 723-735

Benton, D., Owen, D.S. and Parker, P.Y. (1994). Blood Glucose influences memory and attention in young adults. *Neuropsychologia, 32(5),* 595-607

Braver, E.R., Preusser, C.W., Baum, H.M., Beilock, R. and Ulmer, R. (1992). Long hours and Fatigue: A Survey of Tractor-Trailer Drivers. *Journal of Public Health Policy, 13,* 341-366

Brice, C.F. and Smith, A.P. (2002). Effects of caffeine on mood and performance: a study of realistic consumption. *Psychopharmacology, 164,* 188-192

Brown, I.D. (1993). Driver Fatigue and Road Safety. *Alcohol, Drugs and Driving, 9(3-4),* 239-252

Connor, J., Whitlock, G., Norton, R. and Jackson, R. (2001). The role of driver sleepiness in car crashes: a systematic review of epidemiological studies. *Accident Analysis and Prevention, 33,* 31-41

De Valck, E. and Cluydts, R. (2001). Slow-release caffeine as a countermeasure to driver sleepiness induced by partial sleep deprivation. *Journal of Sleep Research, 10,* 203-209

Dinges, D.F. (1995). An overview of sleepiness and accidents. *Journal of Sleep Research, 4(2),* 4-14

Eberhart, R., Hu, X. and Foresman, B.H. (2000). Dangers of Sleepiness and inattention while driving. *Journal of the American Osteopathic Association, 100(8),* S9-S15

Fairclough, S.H. and Graham, R. (1999). Impairment of driving performance caused by sleep deprivation or alcohol: a comparative study. *Human Factors, 41(1),* 118-128

Hall, J.L., Gonder-Frederick, L.A., Chewning, W.W., Silviera, J. and Gold, P.E. (1989). Glucose enhancement of performance on memory tests in young and aged humans. *Neuropsychologia, 27,* 1129-1138

Horne, J. (1992). Stay Awake, Stay Alive. *New Scientist, 1082,* 21-24

Horne, J., Brass, C. and Pettit, A. (1980). Circadian performance differences between morning and evening types, Loughborough Sleep Research Centre, Loughborough University.

Horne, J. and Reyner, L. (1995). Falling Asleep at the Wheel. Loughborough Sleep Research Centre, Loughborough University.

Horne, J. and Reyner, L. (1998). Evaluation of “in-car” countermeasures to sleepiness: cold air and radio. *Sleep, 21,* 46-50

Horne, J. and Reyner, L. (2000). Arrive Alive: Tackling the Problem of Killer Driver Sleepiness. Loughborough Sleep Research Centre, Loughborough University.

Horne, J. and Reyner, L. (2001). Beneficial effects of an “energy drink” given to sleepy drivers. *Amino Acids, 20,* 83-89

Jarvis, M.J. (1993). Does caffeine intact enhance absolute levels of cognitive performance? *Psychopharmacology, 110,* 45-52

Johnson-Koslow, M., Kritz-Silverstien, D., Barrett-Connor, E. and Morton, D. (2002). Coffee Consumption and Cognitive Function among Older Adults. *American Journal of Epidemology, 156,* 842-850

Lobb, S. (1998). Asleep at the Wheel. *Autocar, July*, 55-56

Lamberg, L. (1996). Wake-up call aimed at drowsy drivers: Message is “drive alert, arrive alive.” *Journal of the American Medical Association, 276*, 1209-1210

Mahowald, M.W. (2000). Eyes Wide Shut: The Dangers of Sleepy Driving, *Minnesota Medicine, 83*, 25-30

Mascord, D.J., Walls, J. and Starmer, G.A. (1995). Fatigue and Alcohol: interactive effects on human performance in driving related tasks. In L. Hartley (Ed.) *Fatigue and Driving: Driver Impairment, Driver Fatigue and Driving Simulation.* Taylor and Francis: London

Pack, A.I., Pack, A.M., Rodgman, E., Cucchiara, A.F. and Schwaab, C.W. (1995). Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis and Prevention, 27*, 769-765

Parkes, A.M., Sexton, B.F., Burton, S., Hu, H., Shaw, J.A., and Daggy B.P. (2001). An Evaluation Of The Effects Of A Functional Energy Drink On Post-Lunch And Early Evening Driving Performance. *Driving Assessment 2001 Conference*. Aspen Colorado, August 2001. (CD-ROM)

Parkes, A.M., Burns, P.C., Burton, S., Hu, H., Shaw, J.A., Cotton, J. and Daggy, B.P. (2002). The effects of an energy drink on fatigue and driving performance. *18th World Congress of International Association of Traffic Medicine*. Cairo, Egypt. September 21-24, 2002.

Powell, N.B., Schechtman, K.B., Riley, R.W., Li, K., Troell, R. and Guilleminault, C. (2001). The road to danger: The comparative risks of driving while sleepy. *The Laryngoscope, 111*, 887-893

Reyner, L.A. and Horne, J.A. (2002). Efficacy of a “functional energy drink” in counteracting driver sleepiness. *Physiology and Behaviour, 75*, 331-335

Smit, H.J. and Rogers, P.J. (2000). Effects of low dose caffeine on cognitive performance, mood and thirst in low and higher caffeine consumers. *Psychopharmacology, 152*, 167-173

Stein, A.C. (1995). Detecting fatigued drivers with vehicle simulators. In L. Hartley (Ed.) *Fatigue and Driving.* Taylor & Francis, London.

Stoohs, R.A., Bingham, L., Itoi, A., Guilleminault, C. and Dement, W.C. (1995). Sleep and sleep-disordered breathing in commercial long haul truck drivers. *Chest, 107*, 1275-1282

Yee, B., Campbell, A., Beasley, R. and Neill, A. (2002). Sleep disorders: a potential role in New Zealand motor vehicle accidents. *Internal Medicine Journal, 32*, 297-304

Appendix A. Fatigue review

A.1 The fatigue problem

A.1.1 Definition of sleepiness

Sleepiness and fatigue are considered to be largely subjective psychological concepts and as such have proven very difficult to define. A definition given in Brown (1993) is based on the psychological outcomes of fatigue: "A subjectively experienced disinclination to continue performing the task in hand because of perceived reduction in efficiency".

According to this definition fatigue is dependent on particular task demands. Sleepiness although related to fatigue is not exactly the same thing, despite the fact that it has been used interchangeably in a number of contexts (e.g. Dinges, 1995). Sleepiness, unlike the above definition of fatigue is not necessarily dependent on the task and relates specifically to the desire to sleep rather than any perceived performance decrement on a given task. This review will follow the common practice and use the terms "fatigue" and "sleepiness" synonymously to describe the subjective feeling of the imminent need for sleep, or more precisely "difficulty in maintaining alert wakefulness with a tendency to fall asleep" (Eberhart, Hu and Foresman, 2000).

A.1.2 Types of sleepiness

Some previous research has referred to different categories of sleepiness. These types of sleepiness are physiological, manifest and introspective/perceived sleepiness (Eberhart et al, 2000).

Physiologic sleepiness: The intensity of the drive to fall asleep usually occurring when external stimuli are minimised. This is usually measured by the rapidity of sleep onset in an environment conductive to sleep. Physiologic sleep is primarily affected by the amount of time since the last sleep and in some cases the quality and quantity of that sleep.

Manifest sleepiness: This is the degree of sleepiness an individual experiences when interacting with their environment. The extent of this type of sleepiness is an interaction between the individual's physiologic sleepiness and the properties of the task, principally the degree of environmental stimulation.

Introspective sleepiness: This is a subjective measure that refers to the individual's self-assessment of sleepiness. It is influenced by physiological factors, situational factors and expectation.

A.1.3 General symptoms/deficits caused by sleepiness

The only proven consequence of sleep deprivation is sleepiness. Sleepiness has a number of debilitating effects. These include cognitive and performance deficits as well as abnormal moods. Cognitive performance deficits relate particularly to tasks requiring sustained attention. Creativity, abstract and innovative thinking are impaired when sleepy. Memory also becomes unreliable in sleepy subjects. Mood changes include irritability, negativity and loss of empathy. These impairments can result in problems in the workplace, home, classroom and in particular on the road. The problem is exacerbated by the fact that the magnitude of decrements in performance is not generally related to introspective sleepiness. This limits the extent to which a sleepy individual can compensate for their reduced performance (Mahowald, 2000).

The human body operates according to a number of neurobiologically determined rhythms. The bimodal circadian rhythm governing sleep is governed by the suprachiasmatic nucleus of the hypothalamus. It includes two low points where alertness is naturally low and the desire to sleep is especially salient. These two periods are the early-mid afternoon and the very early morning (typically 4-6am, Horne, 1992). Industrial and work place accidents are most common during these periods as are motor vehicle accidents (Mahowald, 2000). There are several examples of high profile disasters that occurred during the night, for example, Chernobyl nuclear explosion and the grounding of the oil tanker Exxon Valdez (Dinges, 1995). Horne (1992) claims that a driver is 10 times more likely to be involved in an accident if on the road between 4 and 6 am. Other studies have confirmed this conclusion, for example, Akerstedt and Keckland (2001) used data from police records and identified the peak time for motorway accidents as 5 am.

A.2 Driving and sleepiness

A.2.1 Accident Statistics

Sleepiness is considered to be a particular problem for drivers. Reported statistics stating the prevalence of fatigue related accidents vary considerably. It is widely accepted that many estimates are too conservative. There is widespread underreporting fatigue relating incidents. Horne (1992) suggests that accidents that might have been caused by sleepiness are often classified as inattention, failures to look or see and misjudged speed and distance. Despite probable inaccuracies in the statistics it is clear that driver fatigue is a significant safety concern. Table 6 provides a summary of the published statistics on fatigue related incidents around the world. This problem is only likely to increase as society moves increasingly close to a 24-hour society and with the growing trend towards living further away from work and working longer hours.

Motor vehicle crashes caused by drivers falling asleep usually have several distinct characteristics, apart from the fact that they usually occur at the times of day when alertness is naturally low. Seventy-eight percent occur off the road. The majority occur at speeds of greater than 50 mph. (62%). Fall-asleep crashes are usually more serious and a greater proportion result in death or serious injury. This is a fatality rate similar to that of alcohol related crashes. The biggest indicator that the driver fell asleep is the lack of action taken to avoid the crash (Pack, Pack, Rodgman, Cucchiara and Schwaab, 1995). There are usually no skid marks to indicate braking and in most cases only a single vehicle is involved. Lastly, the driver is usually alone in the vehicle (Lamberg, 1996).

Table 6 – Reported Statistics related to accidents involving sleepy drivers

Name and Year	Region	Reported Statistics	Source of Information
Horne & Reyner (2000)	UK	10% of all accidents attributable to sleepiness. 1/5 of accidents on motorways caused by sleepiness. 40,000 serious injuries and 3,500 deaths caused by sleepiness each year. Each death costs £1,000,000.	DETR statistics
Eberhart, Hu & Foresman (2000)	Indiana, USA	23% of people polled reported falling asleep at the wheel on at least one occasion. An estimated 24,000 deaths each year as a result of accidents caused by fatigue.	Quan, Howard, Iber, Kiley, Nieto, O'Connor et al, 1997
Mahowald (2000)	Minnesota, USA	20-31% of crashes are caused by falling asleep at the wheel.	Not stated
Horne (1992)	UK	2% accidents attributed to fatigue in official records compared to 20% perceptual errors.	TRL study
Horne & Reyner, (1995)	UK	20-25% motorway accidents are caused by fatigue. Other nations (USA, Israel and Finland) suffer similar instances of fatigue related incidents.	USA – Langolis, Smolensky, Hsi and Weir, 1986 Israel – Zomer and Lavie, 1990 Finland – Summala and Mikola, 1994
Conner, Whitlock, Norton and Jackson (2001)	USA, France, Australia	1-3% of accidents in USA are thought to be caused by sleepiness. 33% in Australia.	American Medical Association, 1998 Naughton and Peirce, 1991
Mascord, Walls and Starmer (1995)	Australia	20% of accidents in New South Wales and 30% accidents in rural areas can be attributed to fatigue. 77% of drivers rated fatigue as a problem. 85% claimed to experience fatigue occasionally.	Camkin, 1990 Williamson, Feyer, Coumarelos, Jenkins (1992)

Name and Year	**Region**	**Reported Statistics**	**Source of Information**
Lobb (1998)	UK	Up to half of freeway accidents in the USA may be caused by drivers falling asleep. Surveys show that 1/3 British drivers have fallen asleep at the wheel. 80% of shift workers surveyed have fallen asleep. Sleep related crashes may have increased by up to 40% in the years before this paper was published. 30% accidents on French motorways are the result of tiredness.	"American Studies" Not stated RAC French motorway operator
Yee, Campbell, Beasley and Neill (2002)	New Zealand	5.1% of fatal crashes and 5.5% of injury crashes are attributable to fatigue or falling asleep.	Land Transport Safety Authority
Dinges (1995)	Pennsylvania, USA	1-3% or 30,000-90,000 crashes per year in USA are attributable to fatigue. Sleepiness may account for 40% of crashes on long stretches on motorway. 4.4% of all single vehicle roadway involved sleepy drivers.	Knipling and Wang, 1995 Shafer, 1993 General Estimates System and Fatal Accident Reporting System

A.2.2 High risk groups

Mahowald (2000) listed several types of driver who are at increased risk of sleep related motor vehicle crashes:

- *Younger drivers* – Adolescents of driving age are particularly at risk. Older adolescents require more sleep to maintain alertness than younger adolescents. In addition, adolescents find it harder to fall asleep early in the night. This is attributed to a delay in the biological clock that is common in this age group. School and colleges tend to have very early start times and this dictates that adolescents cannot catch up on sleep lost at night by sleeping in in the mornings. Other factors such as extracurricular activities and jobs, increased social commitments and the reluctance of parents to allow sleeping in at the weekends contribute to the increased risk of fall asleep motor vehicle accidents for this group of drivers. It is estimated that 60% of sleep related accidents involve younger drivers of less than 30 years. Other studies have demonstrated an interaction between age and gender. Akerstedt and Keckland (2001) have shown that the night time peak of accidents is more pronounced in young men that young women.
- *Shift workers* – On average night shift workers obtain 8 hours less sleep per week than individuals who work regular hours. The biological clock does not fully adjust to working nights and this situation is even worse when shifts operate on short-cycle patterns, such as one week nights, one week early mornings, one week evenings. In addition, the tolerance to shift work decreases with age making older shift workers even more susceptible to sleep related traffic accidents.
- *Undiagnosed sleep disorders* – There are several sleep disorders that if left untreated pose a serious threat to road safety. The most obvious example is narcolepsy but there are several others. Obstructive sleep apnoea (OSA) occurs in about 4% of adult men and 2% of adult women. During sleep the windpipe closes sufficiently to obstruct breathing causing the sufferer to wake momentarily. The sufferer may never realise that they have had disturbed sleep despite the fact that the disorder results in severe daytime sleepiness. Periodic limb movement syndrome (PLMS) has also been suggested as a possible cause of excessive daytime sleepiness. Yee et al (2002) studied the prevalence of sleep disorders in drivers admitted to hospital after an accident. Thirty-six percent of these drivers were diagnosed with OSA; this is a much greater percentage than the prevalence in the general population indicating that undiagnosed sleep disorders are a cause of motor vehicle crashes.
- *Commercial truckers* – Fatigue is a particular problem for professional drivers. The group at the highest risk is commercial truckers. In the USA trucking is responsible for over 5,000 fatalities and 30,000 casualties per year (Stoohs, Bingham, Itoi, Guilleminault and Dement, 1995). There are several reasons for this. Firstly, although in most nations the number of hours on the road is limited for commercial truckers there are no guidelines as to how to spend the remaining hours. A large number of truckers spend this time loading and unloading or a range of other activities rather than sleeping. In addition, there is a higher than average incidence of OSA in truck drivers, one study found that 46% of their sample were sufferers (Braver, Preuser, Baum, Beilock and Ulmer, 1992)

A.2.3 The comparative risks of fatigue and alcohol

Several studies have attempted to quantify the level of impairment caused by sleepiness by benchmarking it against an accepted benchmark of impaired performance. In most cases fatigued drivers have been compared to alcohol impaired drivers. Alcohol and fatigue impaired groups are similar in a number of respects. They are both basically unaware of the extent of their impairment. The groups were found to be statistically equal on a number of driving performance tasks, including, reactions to signals, hazards and number of cones hit (Powell, Schechtman, Riley, Li, Troell and

Guilleminault, 2001). Other studies have found several differences between alcohol impaired and fatigue impaired drivers. Sleep deprived individuals attempted to compensate for their impairment where alcohol impaired drivers do not. Alcohol impairment leads to a greater number of safety critical errors where fatigued drivers tend to maintain safety critical performance to the detriment of performance factors such as speed control (Fairclough and Graham, 1999). In conclusion, fatigue can cause similar levels of impairment to alcohol consumption although there are a number of qualitative differences. It is worthy of note that in studies where alcohol is compared to sleepiness the fatigued participants have normally been chronically sleep deprived. Therefore these findings relate to deficits caused by unusual levels of sleep deprivation rather than a normal schedule.

A.2.4 Effectiveness of countermeasures

There are a number of countermeasures that drivers employ in order to combat sleepiness while driving. These include opening the window, turning up the radio, taking a walk, drinking coffee and taking a nap. The majority of these measures are ineffective as antidotes to sleepiness. Horne and Reyner (1998) found that the radio and cold air were not successful in increasing driver alertness. Only ingesting caffeine and sleep are effective in reducing sleepiness (Reyner and Horne, 1998).

Appendix B. Previous TRL Driving Simulator Trials

It is worthwhile to trace the development of the methodology used in this study through two previous trials sponsored by GlaxoSmithKline into the effectiveness of various functional energy drinks.

Parkes et al (2001) reports the first study where 24 healthy participants (12 male, 12 female) were tested after consumption of a placebo or an energy drink in a double-blind crossover study.

The energy drink (Solstis®, GlaxoSmithKline, UK) provided 75 mg caffeine and 37.5 g glucose; the placebo was matched for colour, temperature and taste, and both were administered as a single 250ml serving. Each participant was tested after a normal restful night's sleep, in a balanced order on four separate occasions at one-week intervals. Each drink was evaluated during the post lunch dip and during the evening.

As this was the first study conducted in the area a comprehensive approach to data collection was taken in an attempt to build a rich picture of the levels of impairment demonstrated by the participants and to provide a diagnostic capability. Laboratory measures included Useful Field of View (UFOV) and Adaptive Tracking (AT). The simulated drive involved a 40km motorway route. Measures were taken of speed selection and the ability to maintain a constant speed and central lane position during a route of curves of varying radius. Situation Awareness was measured at a point in moderate traffic by blanking the simulation without warning the driver and asking a series of probe questions about the presence and actions of surrounding vehicles. Individual subject sessions lasted for around 150 minutes, including 30 minutes prior to the dose and 120 afterwards. At seven points during the session (three pre-dose) the subject was required to complete the Karolinska Sleepiness Scale, as a self report measure of fatigue.

The results revealed an interesting picture of the effects of the drink. Self report scales of sleepiness revealed a significant difference between consumption of placebo and energy drink ($p < 0.001$). Though both drinks provided an alerting effect immediately after drinking, both the level and duration of the effect of the energy drink was greater.

Performance on the AT task was significantly improved ($p < 0.05$). This improvement in hand-eye coordination was reflected in better lane keeping performance in the simulated driving task ($p < 0.06$).

There was also a consistent tendency ($p < 0.05$) when the drivers drank the placebo, to drive faster in traffic than when drinking the energy drink. Other measures failed to discriminate between the drinks.

These preliminary findings that even a relatively small volume (250ml) of an energy drink could have an effect on sleepiness, lane keeping and speed choice in traffic are important, and if supported by further research could have implications for future highway safety policy.

Given that this was a preliminary study, using an approach geared to assessing gross impairment due to medical and social drug usage, it is not surprising that some tests were better able to discriminate between the drinks than others. Subjective self-report of fatigue state was the clearest measure, and results were in line with those previously reported (Smit and Rogers, 2000). Though both drinks provided an alerting effect, both the level and duration of the effect observed after energy drink consumption was greater.

Performance on the Adaptive Tracking task was significantly better after consumption of the energy drink than after the placebo. This improvement in hand-eye coordination was reflected in better lane keeping performance in the simulated driving task, though the result did not quite achieve statistical significance

There was also a consistent tendency when the participants drank the placebo for them to drive faster in traffic than after drinking the energy drink. Further research is needed to determine if this effect can be replicated, and whether the underlying mechanism is a wish to complete the task quicker, to seek extra stimulation from the drive to counteract the fatigue, or is due to a reduction in the basic ability to interpret speed when more tired. However, the findings on speed and reactions to other traffic were completely consistent with those of Stein (1995). He had drivers given instructions to drive with a threat of a penalty for driving 3 mph over a specified limit, in a Driving Simulator. He found that fatigued drivers were less able to avoid penalties, as their speed tended to drift above the limit, though coarser measures of performance such as collisions with other traffic did not show any differences.

Other measures failed to discriminate between the drinks (UFOV, Situation Awareness, driving at a set speed, and reactions to other vehicles in traffic). This points to a need to increase sensitivity if these measures are to be used successfully in this type of research, where reasonably subtle effects are expected.

The Second Study (Parkes et al, 2002) was also a double-blind, placebo-controlled randomised crossover study and examined the effects of the same energy drink on mental performance and driving. Again the TRL Driving Simulator was used to provide a realistic driving task in a safe and controlled environment. Thirty-six healthy experienced drivers (18 men, 18 women, aged 25-50 yrs) were tested after a normal restful night's sleep and a standardised lunch, on three separate occasions, at one-week intervals. All were tested during the early afternoon when alertness is at a low point. The methods of assessment included subjective sleepiness (Karolinska Sleepiness Scale, KSS), driving performance, overt symptoms of fatigue (eye blinking and yawning) and a set of psychomotor tasks.

This second study sought to improve the sensitivity and diagnostic capability of the first study by increasing the number of participants studied, increasing the performance demands of key driving components (e.g. raising the target speed during curve negotiation) and introducing others expected to better capture changes in behaviour and performance.

On each test day, participants started with a 10-minute baseline drive on simulated motorway and baseline psychomotor tasks, followed by the administration of the energy drink, a matched placebo, or water. The energy drink provided 75 mg of caffeine and 37.5 g carbohydrate (GlaxoSmithKline, Brentford UK). All drinks were administered as a single 250ml serving in a double blind routine. Participants then completed a 70 minute test drive, which had four sections:

1. Motorway with moderate traffic
2. Curving road,
3. Car following
4. A simple reaction time task.

The psychomotor tasks were then repeated. The KSS was administered periodically throughout the test.

After consumption of the energy drink, the drivers demonstrated significantly better driving performance, with less varied speed ($p = 0.02$), better lane keeping ($p < 0.05$), fewer critical incidents ($p < 0.05$) and faster reaction times ($p < 0.01$) when compared to placebo. Participants also reported feeling less tired ($p < 0.001$), their adaptive tracking performance was improved ($p < 0.01$), and they exhibited fewer visible symptoms of fatigue ($p = 0.02$) after drinking the energy drink vs. placebo. Comparisons with water similarly favoured the energy drink.

Results from four sources of data converged to indicate that performance was better and fatigue less with the energy drink than the other drinks.

1. Driving Simulator
2. Laboratory tests
3. Subjective reports
4. Facial indicators.

The results of this study and the first study indicated that this energy drink (75 mg caffeine and 37.5 g glucose) helped sustain driver alertness and reduce the impact of fatigue on driving performance. Taking an energy drink, in conjunction with stopping the vehicle to have a rest, could be an effective strategy to assist drivers in coping with fatigue.

Appendix C. Morningness-Eveningness Questionnaire

MORNINGNESS-EVENINGNESS QUESTIONNAIRE

1 Please read all the questions very carefully before answering

2 Answer ALL questions

3 Answer questions in numerical order

4 Each question should be answered independently of others. Do NOT go back and check your answers

5 Some questions have a selection of answers. For each question place a CROSS alongside ONE answer only.

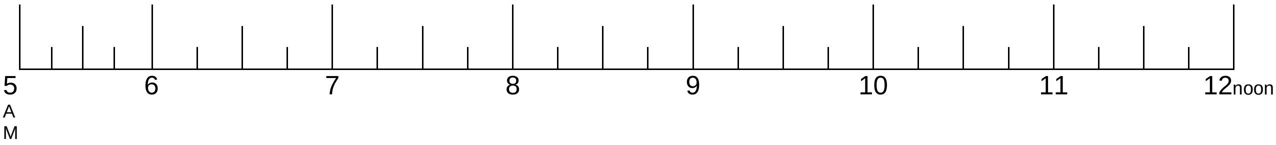
6 Some questions have a scale instead of a selection of answers. Place a cross at the appropriate point along the scale

7 Please answer each question as honestly as possible. Both your answers and the results will be kept in strict confidence

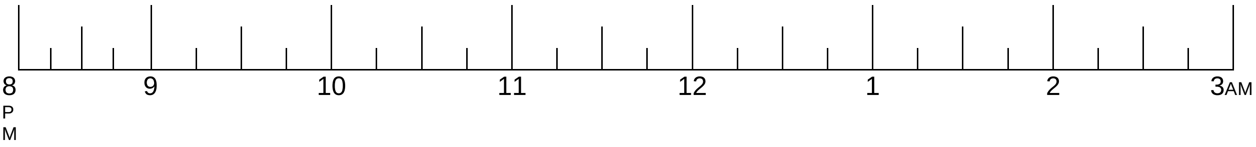
8 Please feel free to make any comments in the section provided below each question

QUESTIONS

1 Considering only your own “feeling best” rhythm, at what time would you get up if you were entirely free to plan your day?



2 Considering only your own “feeling best” rhythm, at what time would you go to bed if you were entirely free to plan your evening?



3 If there is a specific time at which you have to get up in the morning, to what extent are you dependent on being woken by an alarm?

Not at all dependent ☐
Slightly dependent ☐
Fairly dependent ☐
Very dependent ☐

4 Assuming adequate environmental conditions, how easy do you find getting up in the morning?

Not at all easy ☐
Not very easy ☐
Fairly easy ☐
Very easy ☐

5 How alert do you feel during the first half-hour after having woken in the mornings?

Not at all alert ☐
Slightly alert ☐
Fairly alert ☐
Very alert ☐

6 How is your appetite during the first half-hour after having woken in the mornings?

Very poor ☐
Fairly poor ☐
Fairly good ☐
Very good ☐

7 During the first half-hour after having woken in the morning how tired do you feel?

Very tired ☐
Fairly tired ☐
Fairly refreshed ☐
Very refreshed ☐

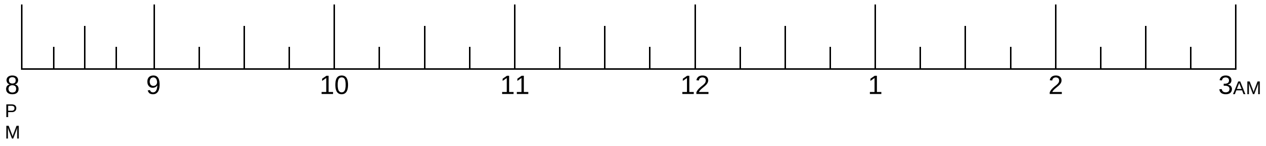
8 When you have no commitments the next day, at what time do you go to bed compared to your usual bedtime?

Seldom or never later ☐
Less than one hour later ☐
1 – 2 hours later ☐
More than 2 hours later ☐

9 You have decided to engage in some physical exercise. A friend suggests that you do this one hour twice a week and the best time for them is between 7:00am and 8:00am. Bearing in mind nothing else but your own "feeling best" rhythm – How do you think that you would perform?

Would be on good form ☐
Would be on reasonable form ☐
Would find it difficult ☐
Would find it very difficult ☐

10 At what time during the evening do you feel tired and as a result in need of sleep?



11 You wish to be in peak performance for a test which you know is going to be mentally exhausting and lasting for 2 hours. You are entirely free to plan your day and considering your own “feeling best” rhythm – Which ONE the four testing times would you choose?

8:00am – 10:00am ☐
11:00am – 1:00pm ☐
3:00pm – 5:00pm ☐
7:00pm – 9:00pm ☐

12 If you went to bed at 11:00pm at what level of tiredness would you be?

Not at all tired ☐
A little tired ☐
Fairly tired ☐
Very tired ☐

13 For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following events are you most likely to experience?

Will wake up at usual time and will NOT fall asleep ☐

Will wake up at usual time and will doze thereafter ☐

Will wake up at usual time but will fall asleep again ☐

Will NOT wake up until later than usual ☐

14 One night you have to remain awake between 4:00 – 6:00am in order to carry out night watch. You have no commitments the next day. Which one of the following alternatives will suit you best?

Would NOT go to bed until watch was over ☐

Would take a nap before and sleep after ☐

Would take a good sleep before and nap after ☐

Would take ALL sleep before watch ☐

15 You have to do 2 hours of hard physical work. You are entirely free to plan your day and considering your own "feeling best" rhythm – Which ONE of the following times would you choose?

8:00am – 10:00am ☐
11:00am – 1:00pm ☐
3:00pm – 5:00pm ☐
7:00pm – 9:00pm ☐

16 You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for them is between 10:00pm and 11:00pm. Bearing in mind nothing else but your own "feeling best" rhythm – How do you think that you would perform?

Would be on good form ☐
Would be on reasonable form ☐
Would find it difficult ☐
Would find it very difficult ☐

17 Suppose that you can choose your work hours. Assume that you work a FIVE hour day (including breaks) and that your job was interesting and paid by results. Which FIVE CONSECUTIVE HOURS would you select?

12 1 2 3 4 5 6 7 8 9 10 12 1 2 3 4 5 6 7 8 9 1 11 12
MIDNIGHT AM MIDDAY PM MIDNIGHT

18 At what time of the day do you think that you reach your "feeling best" peak?

12 1 2 3 4 5 6 7 8 9 10 12 1 2 3 4 5 6 7 8 9 1 11 12
MIDNIGHT AM MIDDAY PM MIDNIGHT

19 One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

Definitely a "morning" type ☐

Rather more a "morning" than and "evening" type ☐

Rather more an "evening" than a "morning" type ☐

Definitely an "evening" type ☐

Appendix D. Schedule

TRIAL DAY ACTIVITY TIMETABLE

Start Time (mins) from arrival	**Activity**
0	Arrival
01	Questionnaire sleep & food preceding 24hrs
03	Sleepiness Scale
05	Baseline Simulator Drive
15	Sleepiness Scale
16	Drink
19	Sleepiness Scale
20	Driving Simulator Trial Session
98	Sleepiness Scale
100	Critical Flicker Fusion Test
105	Choice Reaction Task
110	Adaptive Tracking Test
115	Sleepiness Scale
120	Refreshment & Home

Appendix E. Drink Order Chart

ORDER OF DRINK

	PARTICIPANT	VISIT 1	VISIT 2	VISIT 3					
						01	825	631	343
MALE	06	825	631	343	FEMALE	02	631	343	825
	12	631	343	825		03	343	825	631
	14	343	825	631		05	343	631	825
	17	WITHDREW				04	631	825	343
	18	WITHDREW				07	825	343	631
	21	825	343	631		08	825	631	343
	25	825	631	343		09	631	343	825
	26	631	343	825		10	343	825	631
	27	343	825	631		11	343	631	825
	29	343	631	825		13	631	825	343
	30	631	825	343		15	825	343	631
	31	825	343	631		16	825	631	343
	32	825	631	343		19	631	343	825
	33	631	343	825		20	343	825	631
	34	343	825	631		22	343	631	825
	35	343	631	825		23	631	825	343
	37	631	825	343		24	825	343	631
	38	825	343	631		28	WITHDREW		
	39	825	631	343		36	631	343	825
	40	631	343	825		41	343	825	631
	42	343	825	631		45	343	631	825
	43	343	631	825		47	WITHDREW		
	44	631	825	343		48	WITHDREW		
	46	825	343	631		51	825	631	343
	49	343	631	825		52	631	825	343
	50	631	825	343		53	825	343	631

Appendix F. Instructions

FATIGUE 3 STUDY
NOVEMBER 2002 – MARCH 2003

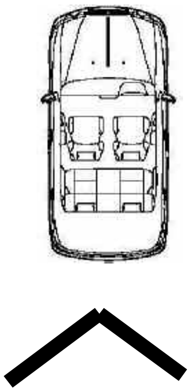
PRACTICE

BY CAR:	Please adjust the seat position and rear view mirrors and fasten the safety belt. I would like to remind you that the vehicle operates with an automatic gearbox – so you just need to use first gear for the whole drive When you come in to take part in trials it is important that you drive as you would normally. We are not here to judge you; we need to see what drivers NORMALLY do. We will start with a practice session of about 10 minutes, to reintroduce you to the driving simulator,
CONTROL ROOM:	The road ahead is a motorway. Please start the car, select first gear, release the hand-brake and drive as you do normally.
ABSCISSA 18000:	You practice drive is now complete. Please reduce your speed to 60mph and travel in the inside lane. This is the first drive of your trial – it will last about 5 minutes. Please try to maintain a speed of 60mph and stay as close to the centre of this left-hand lane as you can.
ABSCISSA	You are now entering a dual carriageway. Please travel at 60mph. Please follow the vehicle ahead at a safe following distance. Are you happy that this is your choice of following distance? The lead vehicle may change speed, but please try to maintain the current distance – no more, no less.
AT THE END:	Thank you that is the end of the session. Please stop the vehicle and, when you bring it to a halt, put the handbrake on, take it out of gear and switch the engine off.

TRIAL SESSION

300:	At some stage during the course of your drive a large red rectangle, like the one in front of you now will suddenly appear. As soon as you see it please flash your headlights so that we can measure your reaction time. The road ahead is a motorway. Please start the engine and drive normally.
30000:	On the sleepiness scale: If 1 is Extremely Alert and 9 is Extremely Sleepy how do you think you feel at this precise moment (check definition of reply/confirm)
45000:	REACTION EVENT
50000:	On the sleepiness scale: If 1 is Extremely Alert and 9 is Extremely Sleepy how do you think you feel at this precise moment (check definition of reply/confirm)
60500:	Please move over to the inside lane. You should now **maintain** a speed of **60mph** and try to stay as close to the **centre** of this **left-hand lane** as you can
70000:	On the sleepiness scale: If 1 is Extremely Alert and 9 is Extremely Sleepy how do you think you feel at this precise moment (check definition of reply/confirm)
71440:	REACTION EVENT
81000:	You are now re-entering the Motorway
81500:	Please approach the vehicle ahead and follow it maintaining 2 chevrons distance
83000: *Speed varies*	The lead vehicle will vary its speed from time to time, but please try to maintain the **current distance** – no more, no less
84000:	Now please check that you are following at a distance of 2 chevrons
84300:	Now please maintain the current distance – no more no less
90000:	On the sleepiness scale: If 1 is Extremely Alert and 9 is Extremely Sleepy how do you think you feel at this precise moment (check definition of reply/confirm)
95000	REACTION EVENT
106000:	You should now drive as you would normally
11000:	On the sleepiness scale: If 1 is Extremely Alert and 9 is Extremely Sleepy how do you think you feel at this precise moment (check definition of reply/confirm)
135000:	REACTION EVENT
13750 *THE END:*	Thank you that is the end of your trial. Please stop the vehicle and, when you bring it to a halt, put the handbrake on, take it out of gear and switch the engine off

FOLLOWING EXERCISE

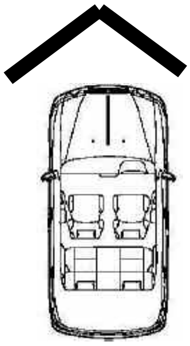


During the course of your Simulator drive today you will be asked to follow a vehicle first of all maintaining a following distance of 2 chevrons (large arrows marked on the road).

Once you have got used to the actual length between you and the lead vehicle you will be asked to follow it maintaining the current DISTANCE – this you should do even though the vehicle then starts to change its speed.

After a short practice you will approach some more chevrons and again asked to check the 2 chevrons following distance.

Finally you will be asked to drive for about 10 minutes maintaining the DISTANCE even though the vehicle changes speed



Note
This exercise is not to find out if you can follow safely at a 2 second gap (which is often the case in Europe), but we want to see whether you can maintain a set following distance – which in actual fact is 60 metres (200ft)

Appendix G. Karolinska Sleepiness Scale

1	Extremely alert
2	
3	Alert
4	
5	Neither alert nor sleepy
6	
7	Sleepy – but no difficulty in keeping awake
8	
9	Extremely sleepy – fighting sleep