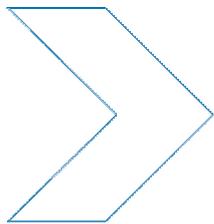


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Review of the literature on coffee stops as a road safety measure

LN Wundersitz, MRJ Baldock

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AUTHORS

LN Wundersitz, MRJ Baldock

PERFORMING ORGANISATION

Centre for Automotive Safety Research
The University of Adelaide
South Australia 5005
AUSTRALIA

SPONSORED BY

Motor Accident Commission
GPO Box 1045
Adelaide SA 5001
AUSTRALIA

AVAILABLE FROM

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ABSTRACT

Caffeine is a widely available mild stimulant thought to promote alertness. It has been suggested that the consumption of caffeine could be promoted at designated 'coffee stops' by the side of the road in rest areas. However, there is some concern that coffee stops might encourage driving when a driver should be resting. Although such roadside initiatives have been operating in Australia and overseas for many years, there are few quantitative evaluations examining the road safety benefits of such programs. Based on empirical research evidence, there is some support for the provision of coffee at roadside rest stops to temporarily alleviate fatigue when driving. However, the combination of drinking caffeine (approximately two cups of coffee) and napping (i.e., 15 minutes) during a break appears to be more beneficial than caffeine alone. Therefore, to enhance the beneficial effects of coffee stops, drivers feeling fatigued should be encouraged to take a 10 to 15 minute nap and to consume coffee. However, even though caffeine has a beneficial effect in alleviating fatigue, these effects are only temporary, lasting for about two hours. Consequently, caffeine alone should not be promoted as a substitute for sleep.

KEYWORDS

Caffeine, Human fatigue, Countermeasures

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Summary

Caffeine is a widely available mild stimulant that is safe to consume at moderate levels. It is thought to promote alertness and so might be a useful countermeasure in reducing fatigue-related crashes. It has been suggested that the consumption of caffeine could be promoted at designated 'coffee stops' located at roadside rest areas. However, there is some concern that coffee stops might encourage driving when a driver should be resting. To address this concern, this report reviewed current research evidence regarding the road safety benefit of providing caffeine at 'coffee stops' as a countermeasure for driver fatigue or sleepiness.

Current empirical evidence indicates relatively low doses of caffeine (100 - 200 mg or approximately two cups of coffee) have been found to improve alertness, cognitive performance, and reduce driving incidents (e.g. lane drifting) on driving simulators. The effects of caffeine are most notable for tasks that are demanding on the information processing system and under suboptimal conditions such as when the individual is fatigued or has a low level of alertness.

While drinking caffeine promotes alertness and can retard the deterioration of driving skills caused by fatigue, the combination of drinking caffeine (two cups of coffee) and napping (i.e., 15 minutes) during a 30-minute break appears to be more beneficial than caffeine alone. However, the beneficial effect of coffee and a nap in alleviating the effects of fatigue is only temporary and dissipates after about two hours. Caffeine has limited beneficial effects for drivers without any sleep. Thus, caffeine is no substitute for sleep; it merely delays the effects of driver fatigue.

There was very little research investigating the value of caffeine in reducing crashes, particularly fatigue-related crashes. However, one study suggested that the consumption of caffeine could reduce crash risk by 50 per cent.

Roadside initiatives that provide coffee for motorists have been operating in Australia and overseas for many years. However, there are few quantitative evaluations of such programs to determine the effectiveness of coffee stops in reducing fatigue-related crashes. One such evaluation of the Queensland Driver Reviver program reported a 31 per cent reduction in fatigue-related fatal crashes and significant savings in social costs.

To summarise, there is some support for the provision of coffee at roadside rest stops to *temporarily* alleviate the effects of fatigue when driving. However, caffeine alone should not be promoted as a substitute for sleep. The beneficial effects of coffee stops can be enhanced by encouraging fatigued or sleepy drivers to take a 10 to 15 minute nap and consume coffee.

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1 Introduction

Driver fatigue is one of the major contributors to road crashes (e.g., Attwell et al, 2001). A number of countermeasures have been proposed to combat the problem of driver fatigue and one of these measures is the consumption of drinks that contain caffeine, such as coffee. Caffeine promotes alertness and thus may reduce fatigue-related crashes. On this basis, consumption of coffee is promoted at designated 'coffee stops' by the side of the road in rest areas.

A number of roadside initiatives promoting the consumption of coffee and other refreshments exist in Australia and overseas (e.g., Driver Reviver). There is some concern that coffee stops might encourage driving when a driver should be resting. Anecdotal evidence suggests that coffee stops are helpful in reducing driver fatigue but quantitative evidence needs to be examined to determine the road safety benefits of such programs.

To address these concerns, this report reviews current research evidence regarding the benefit of consuming caffeine as a countermeasure for driver fatigue. This report begins by briefly examining the concept of driver fatigue, its causes, the prevalence of fatigue-related crashes and potential countermeasures for fatigue once driving. Next, evidence as to whether caffeine can promote alertness and reduce driver fatigue is investigated, in terms of performance on laboratory tasks and driving simulators. Following this, the relative effects of caffeine consumption and napping, another countermeasure for driver fatigue, are compared to determine whether one is more beneficial than the other, particularly in terms of reducing fatigue-related crashes. Finally, existing programs providing coffee at roadside stops are described briefly and any evaluations concerning the effectiveness of these programs are examined.

2 Driver fatigue

2.1 What is fatigue and what causes it?

Philip et al. (2005) define fatigue as “a gradual and cumulative process due to sustained activity and associated with a disinclination towards effort, eventually resulting in reduced performance efficiency” (p. 1511). Sleepiness, a separate concept, is viewed as difficulty in remaining awake and is related to circadian and homeostatic influences. Philip et al. (2005) maintain that while sleepiness disappears after sleep, but not after a rest, fatigue can be eliminated by a period of rest.

However, in Australia, despite the fact that sleepiness and fatigue are separate concepts, the term ‘fatigue’ is often used to refer to both, particularly within the road safety community (Parliamentary Travelsafe Committee, 2005). This is likely to be due to the fact that sleepiness and fatigue often co-occur, and also to the increasing tendency of sleep researchers to draw attention to the role of inadequate sleep and sleep disorders in the development of ‘fatigue’. For this reason, in this report we will follow the convention of using the term ‘fatigue’ to refer to either sleepiness or fatigue. We will only use the term ‘sleepiness’ rather than ‘fatigue’ when discussing studies in which the authors have preferred to use that term. The latter is being done in the interests of accurate representation of source material.

The main causes or precursors of ‘fatigue’ are lack of restorative sleep (includes quality of sleep and time since sleeping), time-of-day (circadian factors), prolonged time on task, heavy workload and under-stimulation (Parliamentary Travelsafe Committee, 2005). These factors are rarely independent of each other and are interactive. Furthermore, fatigue may be affected by factors such as age, physical fitness, personality, the presence of sleep disorders, other medical conditions, alcohol, drugs and environmental stresses such as heat, noise and vibration (Brown, 1994).

Driving is a task that may require sustained attention for a long period of time and may induce fatigue. Studies have linked fatigue to decrements in a number of factors critical to safe driving: vigilance, reaction time, memory, psychomotor coordination, information processing, and decision making (e.g., Rosekind *et al.*, 1996; Stutts, 2000). The obvious implications for driving are that fatigue can lead to decreased attention, which can reduce detection of, and reactions to, potential problems, or can even lead to falling asleep while driving.

2.2 Prevalence of fatigue-related crashes

It is difficult to establish the contribution of fatigue to crash causation because there is no objective measure of fatigue, and crash records are rarely adequate to confirm that fatigue is potentially related to the crash (i.e., no routine records of length of time driving, work schedule or rest breaks). Furthermore, the crash itself may be sufficient to alter arousal levels after the event, or drivers simply may not admit any impairment from fatigue.

In light of these problems, estimates of the proportion of crashes attributable to fatigue generally range from 10 to 40 per cent, with fatal crashes usually at the higher end (Fletcher *et al.*, 2005). The Australian Transport Safety Bureau has formed an operational definition of a fatigue-related crash: single vehicle crashes or head-on collisions not involving overtaking that occur from midnight to 6am or 2pm to 4pm (Dobbie, 2002). Note that crashes occurring on roads with speed limits under 80 km/h and crashes involving alcohol or pedestrians and unlicensed drivers are excluded. Using this definition, they estimated that around 20 per cent of Australian fatal crashes in 2003 were likely to involve driver fatigue (H Savage, personal communication, July 27, 2007) and 14 per cent of injury crashes on a national highway route in 1999 were likely to be fatigue-related (Attwell *et al.*, 2001).

Despite the variation in estimates, it is apparent that fatigue-related crashes are a significant problem in Australia and deserve attention. However, driver fatigue is a difficult issue to address, lacking a universally accepted definition of what it is, lacking a means of measuring it, and thus, lacking a legal framework such as the one that exists for blood alcohol concentrations (e.g., a specified BAC level of 0.05mg/l). Nonetheless, potential countermeasures for driver fatigue have been proposed, and these are discussed in the following section.

2.3 Potential countermeasures for driver fatigue

There are two broad classifications of countermeasures for driver fatigue: countermeasures that reduce the physiological need for sleep and countermeasures that attempt to increase levels of alertness, but really only mask the need for sleep. The best alternative is primary prevention through careful planning, such as getting appropriate sleep before driving and minimising exposure to prolonged driving under monotonous conditions during the time of day of the circadian nadir: 2am to 6am and 2pm to 4pm (MacLean *et al.*, 2003; Nguyen *et al.*, 1998).

Once driving, some drivers choose to turn up music, exercise or open windows to reduce fatigue. However, there is no strong scientific evidence supporting the effectiveness of these measures. One study indicated that listening to the radio provided only temporary effects, effective for only about 15 minutes (Reyner & Horne, 1998a). Similarly, light to moderate exercise increased alertness for only 10 minutes. While heavy exercise improved alertness for about 30 minutes, the regime was not considered to be practical (Horne & Foster, 1995).

The only safe countermeasure for fatigue once driving is to stop driving as soon as possible. Of course, this implies that the driver is aware of their condition. Horne and Reyner (1996) found that drivers were aware of sleepiness prior to major lane drifts in a driving simulator. However, the warning of sleepiness prior to an incident was short. A second study by the same authors (Reyner & Horne, 1998b) clarified that major driving incidents in a driving simulator were always preceded by self-awareness of sleepiness approximately 40 minutes prior. However, not every driver in the study appreciated that they were at the point of falling asleep. Horne and Reyner (1999) argue that self-awareness of driver fatigue and the onset of sleepiness is the best method for a driver to identify the need to increase alertness or stop driving.

In-vehicle technologies have been designed to alert the driver of fatigue. However, fatigue detection technology is not precise, drivers may rely on it and take more risks, and the technology is of little use if the driver is aware of their fatigued state but continues to drive (for a brief discussion see MacLean *et al.*, 2003).

Some agencies advocate that once drivers become aware that they are fatigued, they should "take a break". This is reasonable advice as it forces the driver to stop driving. But what should the driver do once they have stopped driving? According to researchers (e.g., Nelson, 1989), drivers should try napping or consuming caffeine during a break. The effectiveness of these countermeasures is explored in the following sections, beginning with a brief review of napping.

2.4 Napping

Researchers argue that the second best countermeasure for the problem of driver fatigue after primary prevention is behavioural sleep management, particularly napping. There are different opinions as to the optimum nap period for improving alertness. Lisper and Erikson (1980) argue that a nap of five to ten minutes leads to enhanced attentiveness but they found no difference between 15 and 60 minutes of napping. On the basis of a comprehensive review of the literature, Naitoh (1992) concluded that four minutes was the minimum amount of sleep needed to maintain performance. Furthermore, 15-minute naps

taken every six hours during a 35 hour period with no sleep were shown to be useful in maintaining performance. Naps beyond 20 minutes have been found to lead to unwanted post-sleep inertia or grogginess for those unaccustomed to napping, requiring a further 30 minutes to wake fully (Parliamentary Travelsafe Committee, 2005; Dinges, 1992). Based on these findings, Horne and Reyner (1996) argue that that a nap of 15 minutes is optimal.

However, taking a nap is time consuming and needs some planning (i.e., a safe environment). An alternative to napping is the use of behavioural stimulants, the most acceptable being caffeine. The low cost of caffeine and its wide availability suggest caffeine might be a reasonable countermeasure to sustain alertness and performance. The effect of caffeine in reducing driver fatigue is investigated in detail in the next section.

3 Caffeine and its effects

Caffeine is a widely used mild stimulant that occurs naturally in a variety of plants and is consumed through food and beverages made from these plants (e.g., coffee, tea). Caffeine is typically consumed in coffee, and one cup (250ml) of coffee provides approximately 80-110mg of caffeine, although this can vary according to the variety used and the brewing time.

Caffeine has a stimulatory effect on the central nervous system, predominantly by blocking adenosine receptors in the brain (A_1 and A_{2A}). Adenosine is thought to be a potent sleep promoter (Porkka-Heiskanen *et al.*, 1997). Caffeine also increases the levels of some neurotransmitters such as dopamine, acetylcholine and serotonin and increases metabolic rate (see Fredholm *et al.*, 1999 for a review).

There is some concern that the use of caffeine can lead to the development of tolerance, dependency, withdrawal or side effects. A comprehensive review of the central actions of caffeine by Fredholm *et al.* (1999) indicated that there is very little evidence that caffeine used in moderation leads to any significant negative effects on the health of the individual (e.g., increasing risk of cancer, cardiovascular problems). Individuals may suffer from withdrawal symptoms when abstaining from caffeine but these effects are modest and transient, and are generally not experienced when consuming caffeine below a 'moderate' level of 400mg per day (Gray, 1998). Furthermore, caffeine consumers do not gradually increase the dose because tolerance development effects are limited (e.g., Gray, 1998; Wesensten *et al.*, 2005).

Before examining the literature on the effects of caffeine on driver fatigue, some methodological issues associated with the research are discussed.

3.1 Methodological considerations

There are a number of methodological issues associated with research investigating the effects of caffeine that deserve some comment. The use of caffeine in studies is not very consistent (van Duinen *et al.*, 2005). There are variations in the duration of caffeine abstinence, size of dosage, and means of administration (i.e., coffee versus slow-release drugs). Furthermore, different tasks have been selected for performance measures and the amount of sleep deprivation varies. In addition, many of these studies were undertaken among a small sample of healthy young males. Consequently, generalisation of findings to drivers in the general driving population is questionable.

3.2 Effects of caffeine on performance

A number of laboratory studies have investigated the effects of caffeine on various performance measures related to the task of driving but not set in the driving context. The effect of caffeine is most robust on tasks associated with alertness (Brice and Smith, 2002). Caffeine in doses of 200 to 400 mg has been found to increase alertness during a night without sleep (Muehlbach & Walsh, 1995; Penetar *et al.*, 1993). Harrison and Horne (2000) showed that caffeine (350mg) reduced subjective sleepiness in participants deprived of sleep for the previous 35 hours but had no effect on non-sleep deprived participants. All participants were moderate consumers of caffeine (i.e., a daily intake of 100 - 400mg). Relatively low doses of caffeine (100 - 200 mg or approximately two cups of coffee) have also been found to significantly improve self-rated alertness in sleep deprived and fatigued subjects (Lorist *et al.*, 1994; Lumley *et al.*, 1987).

It has been reported that caffeine produces different effects depending on the type of task and the level of alertness of the individual (Smith *et al.*, 2003). Empirical evidence indicates that the effects of caffeine are most notable for tasks that are demanding on the information processing system and under suboptimal conditions such as when the individual is fatigued

or has a low level of alertness. For example, Lorist et al. (1994) reported that caffeine reduced reaction time and increased cortical arousal and perceptual sensitivity. Caffeine had stimulating effects located mainly at the input and output stages of the information processing system; the central processes were unaffected. However, note that caffeine did not have stimulating effects for all subjects. Fatigued participants (i.e., low alertness) showed greater improvements in performance (decrease in error rates) after caffeine than rested subjects.

Other evidence of the beneficial effect of caffeine on information processing comes from studies of cognitive dual-task performance. Cognitive dual-tasks involve the simultaneous execution of two tasks that places high demands on the processing system. Caffeine has a positive effect on the efficiency of the processing system and the allocation of available capacity (Brice & Smith, 2002; Kerr *et al.*, 1991; van Duinen et al., 2005). Van Duinen et al. (2005) showed that a decline in cognitive performance during a fatiguing motor task was partly prevented by caffeine consumption while there was no increase in dual task reaction time. Smith et al. (2003) reported that caffeine improved performance on cognitive vigilance tasks even when individuals had high levels of alertness. In contrast, performance on tasks involving simple reaction time and lapses of attention in choice reaction time improved more when alertness was low.

While caffeine has been found to improve alertness and have positive effects on information processing and cognitive performance, experimental studies have shown that when fatigued, caffeine does not appear to improve episodic memory (Smith *et al.*, 2005), motor performance (van Duinen et al., 2005), or single target and divided attention responses to different parts of the visual field (Mills *et al.*, 2001).

Other researchers argue that the performance enhancing effects of caffeine among regular caffeine consumers are really the removal of negative or detrimental effects of caffeine deprivation, termed a 'withdrawal-reversal effect' (Robelin & Rogers, 1998; Yeomans *et al.*, 2002). This argument is based on the fact that many participants in studies of the effects of caffeine are caffeine users who are typically required to abstain for a period prior to testing. Abstinence from caffeine can have negative effects such as lowered alertness, decreased clear-headedness and impaired psychomotor performance among regular consumers of caffeine (Rogers *et al.*, 2003). This effect can be reversed by a caffeine dose of about 60mg.

The 'withdrawal-reversal effect' hypothesis has received support from studies reporting that additional doses of caffeine during the morning do not give additional boosts to performance. For example, Robelin and Rogers (1998) examined the effects of successive doses of caffeine and found that performance on a simple reaction time task was improved by caffeine when alertness was reduced, and this effect was independent of the dose of caffeine administered. That is, repeated doses did not produce greater effects than the initial dose. In contrast, Brice and Smith (2001b) found clear dose-response patterns based on single administrations of different doses of caffeine.

A very recent study by Hewlett and Smith (2007) found no effect of overnight caffeine withdrawal on mood and performance; high, low and non-caffeine consumers recorded similar baseline measures. Caffeine improved vigilance performance and prevented decreases in alertness, and the size of these effects increased with caffeine dose. Other studies have noted that caffeine had a positive effect in individuals who were only minimally deprived of caffeine (Christopher *et al.*, 2005; Warbuton, 1995; Warbuton & Bersellini, 2001), providing further evidence that the effects of caffeine are not dependent on length of caffeine withdrawal. Hewlett and Smith's (2007) secondary analysis of data collected after a day of normal caffeine consumption confirmed that caffeine had similar effects (i.e., improved performance and alertness) in those who abstained from caffeine more than six hours before testing and those who consumed caffeine up to the time of testing. Alternative explanations are needed that can account for the task specificity of the effects of caffeine and the variation in effects with the level of alertness.

Attwood et al. (2007) suggested that the performance enhancing effects of caffeine were related to levels of habitual intake. High consumers of caffeine (>200mg), but not moderate consumers (<200mg), had faster simple and choice reaction times after caffeine compared to a placebo. These effects were not due to tolerance or withdrawal because both groups had the same baseline measures (mood, negative affect). High consumers were more likely to perceive positive effects.

With respect to caffeine dosage, studies administering a single large dose of caffeine have been criticised because it is not the way in which caffeine is typically consumed when driving (i.e., several small doses). Brice and Smith (2002) demonstrated that caffeine had the same effect when consumed in one large dose compared to a realistic regime of caffeine consumption consisting of many smaller doses. The study methodology ensured that the smaller doses represented the same amount of caffeine present in the body after five hours as for the single large dose. Caffeine contributed to increases in alertness, improved performance on simple and choice reactive tasks, a cognitive vigilance task, a dual task involving tracking and target detection, and a task requiring sustained response.

Note that research has found little evidence of sex differences in behavioural responses to caffeine (Linde, 1995). There is evidence, however, of different effects according to timing of caffeine administration (Wright *et al.*, 1997). The efficiency of caffeine is greatest when consumed at 8pm prior to the onset of melatonin secretion, rather than at 1am to 2am during the peak of the melatonin curve (circadian nadir).

In summary, most empirical results suggest caffeine improves alertness and other tasks related to driving when a driver is fatigued or sleep deprived. However, it is questionable as to whether the effects of caffeine on computerised task performance reflect the effects of caffeine specifically in the driving context. For obvious reasons, there are very few studies evaluating the effects of caffeine on sleep deprived or fatigued drivers in real driving conditions. Studies using driving simulators provide another means for determining whether caffeine is an effective countermeasure for the driver fatigue problem.

3.3 Effects of caffeine on driving

Few driving simulator studies have examined the efficacy of caffeine in alleviating driver fatigue. Of those that have, findings are relatively consistent with the results for laboratory tasks. The consumption of 150 to 200 mg of caffeine (about two cups of coffee) improved driving performance in drivers whose sleep was restricted to five hours the previous night (Horne & Reyner, 1996; Reyner & Horne, 1997). Decreases in major incidents (vehicles leaving the road) and minor incidents (crossing lane markings) in the driving simulator were observed for up to an hour. These studies found that caffeine takes about 30 minutes to take effect.

While the previous studies examined afternoon driving, two other studies investigated the effects of the ingestion of caffeine on early morning driving (i.e., around the time of the circadian nadir) in a driving simulator. Caffeine (200mg) consumed 30 minutes before driving was found to reduce driving incidents (lane drifting) significantly for only the first 30 minutes following no sleep among young experienced drivers (Reyner & Horne, 2000). In fact, these drivers were so impaired that they were unable to continue driving on the simulator after one hour. For those with partial sleep deprivation (i.e., 5 hours sleep the night before), caffeine was beneficial and reduced driving incidents and subjective sleepiness throughout the following two-hour drive. Note that these studies did not have a control group of non-sleep deprived drivers. Nevertheless, these findings indicate that caffeine has limited beneficial effects for drivers without any sleep.

Most of the literature has indicated that the effects of caffeine are strongest when drivers are fatigued and indeed most people consume caffeine at this time to increase alertness and performance efficiency. Brice and Smith (2001a) investigated whether caffeine had any beneficial effects when a driver was unimpaired. As little as 3 mg/kg of caffeine (approximately equivalent to two cups of coffee) improved steering accuracy during a one-

hour drive on a driving simulator for non-fatigued volunteers. Performance on a sustained attention task and measures of mood also demonstrated benefits from caffeine consumption.

3.4 Other forms of caffeine

Apart from coffee, caffeine is available in significant quantities in other beverages and in slow-release drug form. Studies evaluating the effects of energy drinks and slow release caffeine are discussed here.

ENERGY DRINKS

Energy drinks are popular and readily available beverages containing caffeine. Warburton and Bersellini (2001) showed that an energy drink containing caffeine and taurine improved information processing in participants who did not have caffeine withdrawal. Horne and Reyner (2001) investigated whether an energy drink containing caffeine was beneficial in relieving driver fatigue. Based on a small sample ($N=11$) of drivers with restricted sleep, consumption of 500ml of an energy drink containing 160mg of caffeine, glucose flavouring, vitamin B complex, glucuronolactone and taurine was found to significantly improve performance (lane drifting, reaction time) on a driving simulator 30 minutes following ingestion. The effect lasted for approximately 60 minutes. Beneficial effects were most evident during the second half hour after consumption (i.e., 30 – 60 minute period).

Under similar testing conditions, a second study by Reyner and Horne (2002) found that 250 ml of the same energy drink was beneficial in reducing sleep-related driving incidents and subjective sleepiness during the afternoon for the first 90 minutes of a simulated drive. Interestingly, the magnitude of the reduction in driving incidents after consuming the energy drink (80 mg of caffeine) was similar to that found with coffee containing higher amounts of caffeine (150-200mg) under identical experimental conditions. On the basis of this finding, Reyner and Horne (2002) suggest that the energy drinks may be more effective in alleviating sleepiness than caffeine consumed in coffee. However, it is unknown whether other ingredients in the energy drink, specifically the amino acid taurine, may have contributed to the effectiveness of the energy drink in reducing sleepiness. Note also that the company producing the energy drink funded the study.

Given these findings, it appears that further research should be conducted to determine whether providing energy drinks containing caffeine at roadside stops has any beneficial effects on driver fatigue.

SLOW-RELEASE CAFFEINE

In light of the findings that the effects of caffeine dissipate quickly (i.e., 30 minutes if sleep deprived, two hours if partially sleep deprived), some research has investigated whether slow-release caffeine, predominantly administered as a drug, has longer lasting beneficial effects than caffeine typically consumed in coffee. Indeed, a number of studies have demonstrated that 300 to 600mg doses of slow-release caffeine have positive effects on alertness and performance for longer than normal caffeine without any major side effects (Beaumont *et al.*, 2001; De Valck & Cluydts, 2001; Lagarde *et al.*, 2000). These long lasting effects generally peak after four hours and remain at this level for four to six hours.

Beaumont (2001) found that, in comparison to a placebo, the repeated administration of slow-release caffeine (300mg dose given twice daily) during a continuous 64 hour period of wakefulness resulted in longer sleep latency, greater vigilance, and a better level of cognitive performance. The effect of the drug wore off after around 39 hours of sleep deprivation.

De Valck and Cluydts (2001) examined the effect of 300 mg of slow-release caffeine on partially sleep deprived drivers using a driving simulator. Caffeine was found to counteract

the increase in lane drifting and resulted in lower speed deviation and accident liability among sleep deprived drivers (4.5 hours of sleep). Even under more optimal conditions (7.5 hours of sleep), caffeine decreased lane drifting although it did not alter speed deviation or accident liability. The beneficial effect of caffeine was observed one hour after administration and these effects were present after five hours.

Although slow-release caffeine provides a more prolonged beneficial effect than caffeine consumed in coffee, this form of caffeine is expensive and, consequently, would not be practical to administer at roadside stops.

4 Comparing the effects of caffeine and napping

While there is limited research evidence investigating the effects of caffeine *and* napping on driving when fatigued or sleepy (Horne & Reyner, 1999), some studies have compared the relative effects of each in terms of task performance and crash reduction.

4.1 Effects of caffeine and napping on performance and driving

An early study by Walsh et al. (1990) concluded that the increase in alertness after 4 mg/kg of caffeine was similar to the increase in alertness that had been observed after a 3.5 hour afternoon nap in a separate study reported by Sugerman and Walsh (1989). Alertness was measured objectively by two tests measuring physiological sleep latencies. Following this study, Bonnet et al. (1995) compared the effects of varying doses of caffeine and lengths of naps on sustained performance and mood over a 48 hour period of sleep loss. Note that naps in this study were relatively long (2, 4 or 8 hours). It was found that the level of performance, mood and alertness were directly proportional to nap length. Caffeine (400mg) showed peak effectiveness and loss of effect within approximately six hours, whereas naps showed much smaller decay effects over time. However, shorter naps and small repetitive doses of caffeine (150 or 300mg every six hours) did maintain performance, mood and alertness during sleep loss better than no naps or single doses of caffeine. Beyond 24 hours, neither naps nor caffeine could keep performance, mood and alertness near baseline levels. From their results, Bonnett et al. (1995) made a broad generalisation that two to four hour naps had a similar effect to consuming 150 to 300mg of caffeine in terms of the magnitude of improvement. One of the most important findings from this study was that an eight-hour sleep was better in maintaining performance, mood and alertness than either single or smaller repeated doses of caffeine and shorter nap regimes.

While the previous studies compared the effects of naps and caffeine on performance measures, Horne and Reyner conducted a number of studies investigating their effects in the driving context. The first of these studies examined the effects of caffeine (150 mg or two cups) and a short nap (>15mins) taken during a 30-minute break between two one-hour afternoon drives in a driving simulator (Horne & Reyner, 1996). Drivers were partially sleep deprived, having only five hours of sleep the night before. Sleepiness was measured by driving incidents (lane drifting), subjective sleepiness and electroencephalographic (EEG) activity. Caffeine and napping effectively and separately reduced sleepiness in sleep deprived drivers. Simply taking a 30-minute break (placebo condition) was only effective for 15 minutes after driving restarted.

Using a similar study design and measures of sleepiness, a second study examined the effects of a 200 mg dose of caffeine and a combination of caffeine (150 mg) and a 15 minute nap taken during a 30 minute break before a longer afternoon drive (2 hours) on a simulator (Reyner & Horne, 1997). In comparison to a placebo, a mid-afternoon peak in sleepiness was significantly reduced by caffeine alone among sleep deprived drivers for the two hour period. However, the combination of caffeine and a nap was superior to caffeine alone, eliminating the peak in sleepiness and driving incidents. Interestingly, in both of these studies, some participants were unable to sleep but dozed during the nap period ($n=2/10$, $n=4/12$, respectively). Nevertheless, dozing participants still experienced the same benefits.

Performance and sleepiness are more affected by sleep deprivation in a simulated environment than in the real world (Philip et al., 2005). Therefore, the generalisation of results, or at least the magnitude of effects, from driver simulator studies to real world driving is somewhat questionable. Philip and colleagues (2006) are the only researchers, of whom we are aware, to examine the effects of caffeine and napping on night time driving performance in a real life setting. They conducted a randomised, double-blind, cross-over study among a small sample of well rested young males ($N=12$). Participants received 200mg of caffeine, a placebo, or took a 30-minute nap before a 200km drive on a highway in four sessions (one during daylight, three from 2am to 3:30am). Drivers with a history of

substance abuse or pre-existing sleep disorders were excluded. Impaired driving (line crossings) occurred significantly less frequently after caffeine and after a nap than the placebo. The incident rate ratio for having a line crossing was 3.7:1 after the placebo compared with coffee, and 2.9:1 after the placebo compared with napping. There was no significant difference in driving impairment between consuming caffeine and napping. Caffeine and napping also significantly reduced self-rated sleepiness but not self-rated fatigue. Of interest, subsequent sleep latencies (time taken to fall asleep) and efficiencies (time spent sleeping) were similar in all three conditions suggesting that consuming caffeine and napping at night time reduced impaired driving without affecting subsequent sleep.

Note that there was some variability in the response of participants to caffeine and napping in this study. Based on this observation and the fact that both countermeasures were approximately equally beneficial in reducing line crossings, the authors do not recommend one measure over the other. Further research is needed to show whether these effects can also be found for different doses of caffeine, varying durations of sleep, greater consumers of caffeine, older drivers, or sleep deprived drivers.

4.2 Effects of caffeine and napping on crashes

Research examining the effects of napping and the use of caffeine on crashes, particularly fatigue-related crashes, would provide the most convincing evidence as to whether they are beneficial in road safety terms. However, very few studies have attempted to do this, most likely due to the problem of identifying fatigue-related crashes.

One study used a case-control research design to compare measures used to prevent fatigue-related crashes among four different groups of drivers: those involved in sleep crashes, fatigue crashes, other crashes, and no crashes (Stutts *et al.*, 1999). All crashes were reported to police in North Carolina and identified as 'sleep' or 'fatigue' crashes by the investigating officer. Drivers previously involved in sleep and fatigue crashes were more likely to report drinking caffeine to promote alertness while driving (17.3% and 17.4%, respectively) than non-crash drivers (12.5%). Sleep and fatigue crash drivers were also more likely than control or non-crash drivers to mention stopping for a nap (12.2%, 12.3% vs. 7.2%, 4.7%, respectively). When asked about their satisfaction with these measures, sleep and fatigue crash involved drivers were less likely to rate consuming a beverage with caffeine as "very helpful" in comparison to stopping for a rest or a nap. Note that it is likely that the experience of being involved in a sleep or fatigue crash has altered the strategies adopted by these drivers.

We only found one study that specifically investigated how factors that might counteract drowsiness are related to crash risk. Cummings *et al.* (2001) conducted a case-control study in the United States. Crash involved drivers (not necessarily fatigue-related crashes) and controls were interviewed to obtain information about driving exposure (including driver drowsiness related exposure), factors that might counteract driver drowsiness and potential confounding variables. Among other things, it was found that crash risk decreased for drivers who used a highway rest stop (adjusted relative risk=0.5, CI 0.3 – 1.0) and drivers who drank coffee within the last two hours (adjusted relative risk=0.5, CI 0.3 – 0.9).

The finding that caffeine reduces crash risk was consistent with findings from driver simulator studies, although the level of caffeine consumed by drivers in Cummings *et al.*'s study was not measured. Of interest, soft drinks containing caffeine did not have a protective effect. This finding was attributed to the fact that coffee contains more caffeine per ounce than soft drinks (i.e., 17 mg versus 4 mg, respectively, see Shils *et al.*, 1998).

5 Evaluations of coffee stops

Empirical research suggests that there may be some road safety benefits associated with the provision of coffee at roadside rest stops. However, there is concern that the consumption of caffeine might encourage driving when the driver should be resting. Compensation theories suggest that when a situation is made inherently safer, individuals may behave in a riskier manner because the overall risk that they are willing to accept remains the same (De Valck & Cluydts, 2001). Essentially, individuals driving in suboptimal conditions will continue to do so, trying to keep performance at a baseline level. Thus, based on compensation theory, drivers consuming caffeine might continue driving for a longer period than they would without caffeine. As a consequence, crash risk is not reduced. Comprehensive evaluations of existing coffee stop programs are needed to provide evidence of their usefulness in reducing the effects of driver fatigue and fatigue-related crashes.

A number of roadside initiatives promoting the consumption of coffee and other refreshments exist in Australia and overseas. For example, the national Driver Reviver program in Australia encourages drivers to 'stop, revive, survive' at sites located in rest areas or at service stations on major highways. Free coffee and/or tea and a light snack are offered at the sites. This program is limited to operating predominantly during school holidays and some long weekends, dependent on the availability of volunteers from the local community that staff the sites. The program is funded by various government agencies in each state with snacks and beverages sponsored by private organisations (e.g., Bushells, Arnotts).

In addition to Driver Reviver, a "Coffee Stop" program operates the entire year in Western Australia and the Northern Territory (Parliamentary Travelsafe Committee, 2005). In this program, participating roadhouses offer a free cup of coffee to drivers on long journeys. The program is provided as a sit down service to ensure drivers take a break from driving. Roadhouses do not receive any reimbursement for the service they provide and so are financially contributing to this program. These roadside initiatives designed to reduce driver fatigue have been operating in Australia for many years. Although we found several studies focussing on the patronage of these programs, there were few evaluations that quantified their effectiveness in reducing driver sleepiness and fatigue-related crashes.

One such evaluation examined the effectiveness of the Queensland Driver Reviver program, for the period 1999 to 2001, in terms of fatigue crash reductions and total social costs (Meers, 2002). Trends in fatigue-related crashes occurring within 100 kilometres of a driver reviver site during Queensland school holidays were compared to trends for all other fatigue crashes (i.e., crashes not within 100km of driver reviver sites, occurring at times other than school holidays). A fatigue crash was defined as one that was identified as such by the reporting police officer or a crash that occurred within a 100km/h speed zone during the fatigue hours of 2pm to 4pm or 10pm to 6am, involving overturning or running off the road. Note that identifying a fatigue crash is difficult given that crash records are rarely adequate to confirm that fatigue is potentially related to the crash.

Results from the crash analysis estimated a saving of 10.4 lives (31% reduction in fatal crashes) and \$4.1 million in social costs (the calculations used to determine social costs were not specified). The analysis showed some increases in crashes of other severities during the three-year post-treatment period but these were not statistically significant. Queensland Transport recently undertook another evaluation of the Queensland driver reviver initiative but the results are not yet available.

Although not specifically evaluating the Driver Reviver program, Cercarelli and Ryan (1997) examined the characteristics of drivers stopping at Driver-Reviver sites in Western Australia. In general, drivers most likely to have fatigue-related crashes are aged under 30 years (Horne & Reyner, 1995), whereas the median age group for drivers interviewed at driver-reviver sites was slightly older: 30 to 39 years. Higher self-reported fatigue levels

among drivers interviewed were associated with greater distances driven and time spent driving that day. Of interest, subjective ratings of fatigue showed that most drivers stopping at the Driver-Reviver sites were not fatigued (although it is possible that the fact drivers had already stopped driving slightly revived them). Moreover, drivers reported a reasonable amount of sleep the previous night (mean of 7.1 hours). Thus, it appears that drivers who stop at driver-reviver stops are probably more cautious than those who do not stop. In other words, it is possible that the severely fatigued drivers who really need the roadside stops providing coffee are not using them.

Similar research was conducted in New South Wales more recently, focusing on patronage at Driver Reviver sites rather than the effectiveness of the program (J Simpson, personal communication, July 23, 2007). The characteristics of drivers stopping at driver reviver sites were compared to those of drivers stopping at commercial outlets operating near driver reviver sites (control sites). Drivers stopping at driver reviver sites were on longer trips (mean=4 hours and 11 minutes) than those stopping at control sites (mean=3 hours and 25 minutes) and would take longer breaks. Drivers stopping at driver reviver sites were also more likely to stop for something to drink and to have a rest break. Given that driver reviver sites operate during holiday periods, it was not surprising that 90 per cent of drivers stopping at driver reviver sites were leisure travellers (80% at control sites). Many drivers had used the driver reviver sites previously; nearly half of the drivers reported that they were regular visitors and around 25 per cent said they occasionally visit them when on holidays.

Similar roadside schemes, aiming to reduce driver fatigue, operate overseas. For example, in New York State, the Thruway Authority has offered free coffee and tea to motorists travelling during the New Year holiday period for more than 40 years (Buono & Fleischer, 2007). The free beverages are provided at 27 travel plazas throughout the state. However, we were unable to find any formal evaluations of this scheme.

Despite the prevalence of roadside initiatives providing coffee and other beverages, there is still a need for more formal evaluations of these schemes to quantify their effectiveness in terms of reducing fatigue-related crashes.

6 Summary and Conclusions

Caffeine is a widely available mild stimulant that is safe to consume at moderate levels. Current empirical evidence indicates relatively low doses of caffeine (100 - 200 mg or approximately two cups of coffee) have been found to improve alertness, cognitive performance, and reduce driving incidents (e.g., lane drifting) on driving simulators. The effects of caffeine are most notable for tasks that are demanding on the information processing system and under suboptimal conditions such as when the individual is fatigued or has a low level of alertness.

While the research shows that drinking caffeine promotes alertness and can impede the deterioration of driving skills caused by fatigue, the combination of drinking caffeine (two cups of coffee) and napping (15 minutes) during a 30-minute break appears to be more beneficial than caffeine alone. However, the beneficial effect of coffee and a nap in alleviating the effects of fatigue is only temporary and dissipates after about two hours. Caffeine has limited beneficial effects for drivers without any sleep. Thus, caffeine is no substitute for sleep; it merely delays the effects of driver fatigue.

There was very little research investigating the value of caffeine in reducing crashes, particularly fatigue-related crashes. However, one study found that the consumption of caffeine could reduce crash risk by 50 per cent.

Roadside initiatives that provide coffee for motorists have been operating in Australia and overseas for many years. However, there are few quantitative evaluations of such programs to determine the effectiveness of coffee stops in reducing fatigue-related crashes. One such evaluation of the Queensland Driver Reviver program reported a 31 per cent reduction in fatigue-related fatal crashes and significant savings in social costs.

To summarise, there is some support for the effectiveness of providing coffee at roadside rest stops to *temporarily* alleviate the effects of fatigue when driving. However, caffeine alone should not be promoted as a substitute for sleep. The beneficial effects of coffee stops can be enhanced by encouraging fatigued or sleepy drivers to take a 10 to 15 minute nap and consume coffee.

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