Transportation Research Part F 54 (2018) 236–247

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Caffeine reduces the impact of drowsiness on driving errors

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ARTICLE INFO

Article history:
Received 15 May 2016
Received in revised form 23 September 2016
Accepted 14 January 2018

Keywords:
Drowsiness
Driving performance errors
Sleep loss
Caffeine

ABSTRACT

Aim: The study examined the moderating effect of repeat-dose, chewing gum-administered caffeine on the well-established relationship between drowsiness and driving performance, under the conditions of accumulating sleep loss.
Method: 50-h sleep deprivation protocol with a double-blind, placebo-controlled design. Eleven volunteers (6 male), aged 18–28 years were screened for pre-existing medical conditions (including sleep disturbances), tobacco and recreational drug use, recent time-zone travel and shift-work. They were randomly allocated to placebo or caffeine group and administered 4 oral doses of either caffeinated gum pellets (200 mg/dose) or non-caffeinated placebo gum every two hours (01:00, 03:00, 05:00, 07:00) on the first and second nights of the protocol. Participants were constantly monitored and remained awake for 50 h, while performing 15 identical, evenly-spaced 40-min monotonous driving tasks in a medium-fidelity moving-base driving simulator. Their drowsiness was monitored with a spectacle frame-mounted infra-red sensor registering ocular parameters and converting them into a Johns Drowsiness Scale (JDS) score every 60 s. Lane keeping and speed variability measures were used to assess driving performance.
Results: Driving performance declined and drowsiness increased from the first simulated drive to the last. When driving performance was examined in one-minute epochs synchronised with JDS scores, both lateral lane positioning and speed variability were found to be associated with drowsiness. The strength of this association was significantly weaker in the caffeine group, compared to placebo. Placebo group replicated the linear relationship between drowsiness and driving errors across the full range of JDS scores. This pattern was significantly weaker under the caffeine condition, and was even reversed at the upper range of JDS, with higher JDS scores not resulting in further degradation of driving performance. This dissociation between drowsiness and driving errors persisted across the 24-h cycle under the caffeine condition, despite caffeine being administered only during early morning hours.
Conclusion: Strategically timed, repeat 200 mg doses of caffeine administered via chewing gum can mitigate fatigue-induced impairments in driving performance by not only reducing drowsiness but also by significantly weakening its impact on driving errors. This dual effect of sustained drowsiness reduction and the dissociation between drowsiness levels

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https://doi.org/10.1016/j.trf.2018.01.008
1369-8478/

and driving errors seems worth further investigation as it might offer an effective emergency countermeasure against driver drowsiness and its subsequent conversion into potentially fatal driving errors.

1. Introduction

Driver drowsiness is a major contributor to road accident risk (Horne & Reyner, 1995a, 1995b; Johns, 2000). It is an important general risk factor among regular commuter drivers (Horne & Reyner, 1995a, 1995b), with driver fatigue accounting for 24.9% of fatal accidents among the general population on Australian roads (Dobbie, 2002). Drowsy drivers have been found to be almost three times more likely to be involved in a crash or near crash compared to alert drivers (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Drowsiness is even more critical to professional driving populations (Maycock, 1997), especially to those involved in continuous operations such as mining (Mabbott & Lloyd, 2006), long-haul transport (Mitler, Miller, Lipsitz, Walsh, & Wylie, 1997) and the military (Murphy, 2002). Sleep deprivation has been widely recognised as a significant risk factor in transport industry for serious accidents and fatalities (Banks, Catcheside, Lack, Grunstein, & McEvoy, 2004; Banks & Dinges, 2007; Biggs et al., 2007; Gore, Webb, & Hermes, 2010; Horne & Reyner, 1995a, 1995b; Mets, van Boven, & Verster, 2012; Van Dongen, Rogers, & Dinges, 2003; Williamson et al., 2011). Both accumulating sleep loss and continuous wakefulness (sleep deprivation) make it difficult to stay awake, even when performing various tasks. This transient state is known as 'sleepiness' (Philip, Sagaspe, Moore et al., 2005), with drowsiness reflecting the period of unstable, rapidly fluctuating state of sleepiness and the associated performance impairment (Anderson & Horne, 2013; Johns, Tucker, Chapman, Crowley, & Michael, 2007; Moorcroft, 2013).

Performance decline in several cognitive domains including attention and vigilance, visual processes, processing speed and reaction time, working memory and executive function, have been associated with crash risk both in on-road driving and simulator-based studies (Anstey, Wood, Lord, & Walker, 2005; Jackson, Croft, Kennedy, Owens, & Howard, 2013). Similar declines characterise neurocognitive impairments observed under sleep deprivation (Jackson & Van Dongen, 2011; Koslowsky & Babkoff, 1992), with attention and psychomotor vigilance being more vulnerable to sleep-loss-induced decline than higher-order capacities such as executive functioning (Jackson et al., 2013).

With mounting evidence linking driver drowsiness to road accident risk, the search for countermeasures and mitigation strategies has expanded exponentially, and now covers a broad range of shift-work regulation, driver monitoring and adaptive driver assistance systems (ADAS), and pharmaceutical interventions. The latter range from heavy-duty drugs to low-risk substances such as caffeine. Caffeine is one of the most widely consumed substances in the world and is known for its sleepiness-mitigation properties (Heckman, Weil, & De Mejia, 2010). Caffeine is also known to have little or no adverse effect on health below doses of 450 mg per day (Fredholm, Bättig, Holmén, Nehlig, & Zvartau, 1999; Heckman et al., 2010). So its regular consumption is considered to be safe. For example, a recent large survey showed an average Australian consumes 232 mg of caffeine per day, equating to approximately 5 small cups of medium strength instant coffee or 1–2 barista-prepared coffees (Heckman et al., 2010).

The effectiveness of caffeine in reducing the impact of sleep deprivation on alertness, vigilance and cognitive performance is well established (Bonnet & Arand, 1994; Penetar et al., 1993; Reyner & Horne, 2000; Van Dongen et al., 2001; Wesensten, Belenky, Thorne, Kautz, & Balkin, 2004; Wesensten, Killgore, & Balkin, 2005; Wesensten et al., 2002). In particular, caffeine has been shown to reduce sleep-loss-induced deficits in alertness and vigilance (Benitez, Kamimori, Balkin, Greene, & Johnson, 2009; Lorist & Snel, 2008; Snel, Tieges, & Lorist, 2004) with effects ranging from simple psychomotor tasks to executive functioning (Balkin et al., 2004; Wesensten et al., 2002, 2004, 2005). Caffeine has also been shown to mitigate against low arousal, boredom and monotony (Brice & Smith, 2001; McLellan et al., 2005; Michael, Johns, Owen, & Patterson, 2008), with doses as low as 3 mg/kg shown to reduce drowsiness and improve steering accuracy during simulated monotonous driving (Brice & Smith, 2001). Caffeine has been shown to assist with performance maintenance in military operations (Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Lieberman et al., 2005; Tharion, Shukitt-Hale, & Lieberman, 2003), particularly during periods of sleep deprivation (McLellan et al., 2005). However, the relative efficacy of varying dosages and administration regimes remain unclear. For example, single 100 mg doses have been found to improve subjective sleepiness (Reyner & Horne, 2000) and simulated driving performance (Biggs et al., 2007) following sleep restriction, but for relatively short periods only, with effects lasting between 30 min and one hour post-consumption (Biggs et al., 2007; Reyner & Horne, 2000). The duration of these low-dose effects is clearly insufficient for sustained operations. Repeat moderate doses (up to 200 mg caffeine per dose) have shown greater utility than single-dose protocols, with longer effect duration and reduced side effects (Dark, Kamimori, LaValle Christina, & Eonta, 2015). The superior efficacy of repeat moderate-dose regimes has been demonstrated in maintaining performance on both laboratory cognitive tests (Dark et al., 2015; Paech et al., 2016) and operational tasks (McLellan et al., 2005).

While caffeine has a well-established capacity to moderate the global decline in alertness across extended periods of continuous wakefulness, its impact on moment-to-moment fluctuation of alertness is less known. Yet it is these momentary drowsiness spikes and subsequent lapses of attention that pose the greatest risk to sleep-deprived drivers. To account for