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Name that tune: Mitigation of driver fatigue via a song naming game

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ABSTRACT

Fatigued driving contributes to a substantial number of motor vehicle accidents each year. Music listening is often employed as a countermeasure during driving in order to mitigate the effects of fatigue. Though music listening has been established as a distractor in the sense that it increases cognitive load during driving, it is possible that increased cognitive load is desirable under particular circumstances. For instance, during situations that typically result in cognitive underload, such as driving in a low-traffic monotonous stretch of highway, it may be beneficial for cognitive load to increase, thereby necessitating allocation of greater cognitive resources to the task of driving and attenuating fatigue. In the current study, we employed a song-naming game as a countermeasure to fatigued driving in a simulated monotonous environment. During the first driving session, we established that driving performance deteriorates in the absence of an intervention following 30 min of simulated driving. During the second session, we found that a song-naming game employed at the point of fatigue onset was an effective countermeasure, as reflected by simulated driving performance that met or exceeded fresh driving behavior and was significantly better relative to fatigued performance during the first driving session.

Safe operation of a motor vehicle at highway speeds requires mental alertness (Shinar, 1993). Impairment due to driver fatigue accounts for approximately 40% of road accidents in North America (McCartt et al., 1996), and naturalistic driving research estimates that driving while drowsy increases crash or near-crash risk by five-fold (Klauer et al., 2006). The consequences of fatigue-related crashes are often severe, and there is typically no sign that the driver attempted to stop the crash (Horne and Reyner, 1995; National Highway Traffic Safety Administration, 1998). Such accidents are commonly characterized by a single vehicle occupant operating in a monotonous environment, such as a straight road with homogenous scenery (Horne and Reyner, 1995; Sagberg, 1999; Thiffault and Bergeron, 2003). Additional factors associated with increased fatigue include increased duration of driving (Nilsson et al., 1997; Ranney et al., 1999; Van der Hulst et al., 2001), sleep deprivation (Otmani et al., 2005), and drug and alcohol use (Hack et al., 2001). Disruption of circadian rhythms may also play a role, as accidents attributed to sleeping drivers occur most often during the nighttime and early morning hours (Pack et al., 1995).

Drivers will often implement compensatory strategies to mitigate the influence of distractors (Young et al., 2007). For instance, during periods of high cognitive load, drivers may use behavioral strategies such as decreasing traveling speed or increasing the distance between themselves and leading vehicles (Lansdown et al., 2004; North and Hargreaves, 1999; Strayer and Drews, 2004; Törnros and Bolling, 2006). Robert and Hockey (1997) has proposed that in addition to implementing behavioral strategies, drivers may regulate mental effort to compensate for the presence of distractors. Listening to music while driving is a common behavior, and drivers often cite concentration benefits and fatigue mitigation as a justification for engaging in music listening (Dibben and Williamson, 2007; Nguyen et al., 1998), suggesting that listening to music may be an attempt to regulate cognitive resources during driving performance. In a simulator study, Reyner and Horne (1998) found that participants suffering from lack of sleep benefitted more from listening to the radio than from having cold air blown into the face, providing support for the idea that music listening may mitigate fatigue, at least as a temporary countermeasure.

Several studies, however, indicate that listening to music during motor vehicle operation increases the mental effort required to adequately perform the primary task of driving and is therefore considered a distraction (Cassidy and MacDonald, 2010; Ünal and Steg, 2012). A large survey (N = 1780) of British drivers indicates a positive correlation between lack of motor insurance claims and preference for driving in silence (Dibben and Williamson, 2007). Due to the familiar nature of listening to music while driving (North et al., 2004) and because drivers listening to music may perform as well as those driving in silence despite increased mental load under some circumstances (Ünal

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and Steg, 2012), drivers often do not perceive music as a distraction (Dibben and Williamson, 2007).

Cognitive effort is metabolically intense (Fairclough and Houston, 2004; Kennedy and Scholey, 2000) and people typically attempt to use the minimum amount of cognitive effort necessary to perform a task, or avoid cognitive demand when possible (Kool et al., 2010; Westbrook and Braver, 2015). As drivers are capable of regulating mental effort in order to maintain driving performance (Ünal and Steg, 2012), driving may therefore be thought of as a resource-limited task, in that performance may be improved via allocation of additional cognitive resources (Norman and Bobrow, 1975). In contrast to highly complex traffic environments which increase cognitive demand for drivers (Baldwin and Coyne, 2003; Horberry et al., 2006; Strayer et al., 2003; Ünal and Steg, 2012), fatigue effects appear to be exacerbated by conditions of cognitive underload, such as monotonous highway driving along a straight road in low density traffic (Matthews and Desmond, 2002).

Under circumstances that typify cognitive underload, requiring greater mental effort by introducing a mild distractor may mitigate performance impairments related to fatigue and boredom. The finding that in certain contexts listening to music while driving provides performance benefit supports this notion. Cassidy and MacDonald (2010) found that self-selected music increased accuracy during performance of a driving game. found that ability to follow a lead car with an irregular driving pattern and accident avoidance due to the sudden appearance of another vehicle improved when drivers were listening to music. Atchley and Chan (2011) demonstrated that introduction of a secondary task may alleviate monotony and increase vigilance during a simulated driving experience.

In contrast to the findings of Dibben and Williamson (2007) which indicate a positive relationship between music listening and motor insurance claims, a study using a data set restricted to rural highway driving found that crash risk was reduced when a sound system was active (Cummings et al., 2001).

These findings indicate driving context matters when evaluating the impact of music on performance, and provide support for Hockey's (1997) model of compensatory cognitive control, suggesting that regulation of mental effort is a strategy employed by drivers in order to compensate for secondary task demands and distractors. Non-distracting secondary tasks can be described as those tasks that require few cognitive, perceptual, and/or motor resources from the driver to actively perform. Engagement with this type of task while driving should not significantly affect performance compared to conditions in which drivers do not engage in secondary task performance.

Driving simulators enable researchers to evaluate the impact of interventions on driving behavior (e.g., Atchley and Chan, 2011; Brodsky, 2001; Cassidy and MacDonald, 2010; Matthews and Desmond, 2002; Merat and Jamson, 2013; North, and Hargreaves, 1999) rather than assessing cognitive functioning that may relate to driving performance (e.g., response times, attention, perception). In the current study, we used a simulated driving experience in order to evaluate the impact of a song-naming game on driving performance in the context of monotonous highway driving. Prior research has indicated fatigue-related behavior occurs in 30 min or less of driving in a monotonous environment (Merat and Jamson, 2013; Thiffault and Bergeron, 2003). The current study used a one-hour stretch of driving along a monotonous highway environment, allowing for 30 min of observation following the likely onset of fatigued behavior. Drivers were observed during two days of simulated driving, with the first visit verifying that fatigue effects become apparent following 30 min of driving, and the intervention applied following 30 min of driving during the second day. This allowed a comparison between fatigued driving during the last 30 min of driving on the first day (no intervention) and fatigued driving in the presence of the intervention during the last 30 min of the second day. This design has previously been used to effectively examine the impact of interventions on fatigued driving performance (Merat and Jamson, 2013).

We hypothesized that results would indicate the following: (1) driving performance deteriorates during the second 30 min of driving on the first day relative to the first 30 min of driving, establishing that fatigue, operationally defined as said performance deterioration, is evident in this paradigm in the absence of an intervention; (2) performance does not significantly deteriorate during the second 30 min of driving on the second day relative to the first 30 min of driving on the second day, due to the intervention; (3) performance is significantly better for the second 30 min of driving on the second day (fatigued driving with an intervention) relative to the second 30 min of driving on the first day (fatigued driving with no intervention).

1. Experiment 1

1.1. Methods

1.1.1. Participants

Twelve male and 13 female employees from Sandia National Labs participated in this study (age range: 22–56, M = 39.16, SD = 11.84). All participants reported having normal or corrected to normal vision and no visual, auditory, or motor deficits. Participants reported having an average of 22.65 years of driving experience and an average of 0.16 at-fault accidents over the past three years. In addition, participants reported an average of 0.54 speeding citations. Participants drove in a simulated environment for a continuous 1-h period on each of two consecutive, permitting an analysis of four half-hour blocks of driving: Block 1–baseline driving performance on Day 1; Block 2 (Day 1) − fatigued driving performance on Day 1; Block 3–baseline driving performance on Day 2; and Block 4–fatigued driving performance with a music intervention on Day 2. Participants also reported their sleep duration for the night preceding study participation.

1.1.2. Materials and apparatus

The STISIM-Drive driving simulator, developed by Systems Technology Inc., was used to measure and document participants' driving behaviors. The simulator replicated an automatic transmission car and consisted of a steering wheel, an acceleration pedal, and a brake pedal. A 24-inch LCD monitor mounted on a desktop provided the visual scenes, which played at a rate of 30 frames per second. The software was PC-based and operated in a Windows interface. It also provided immediate visual and auditory feedback about roadway events and recorded driver performance in terms of reaction times, average headway, average lane position, and average speed.

The vehicle was modeled after a red Buick coupe and had clear views out of the front windshield and rearview mirrors. Side view mirrors were disabled during the experiment. Vehicle simple linear dynamics were utilized and modeled real-life driving conditions. The yaw rate scale factor was set to 0.0002 Rad/Sec/Deg. The acceleration and deceleration limits were set to 0.35 g and −0.28 g, respectively. These are considered moderate acceleration and braking limits (Fricke et al., 2010).

Participants drove along a four-lane rural highway without traffic, curved slightly to the right and to the left at random intervals throughout the experiment. The roadway environment was purposefully not stimulating and therefore trees, pedestrians, and buildings were not included in the scenario design. A sign indicating the speed limit (55 mph) appeared every 5000 feet of simulated driving distance. During random intervals throughout the experiment, participants experienced subtle wind gusts modeled as pseudorandom disturbances specified by multiple sine waves that caused their vehicle to drift into the next lane. These gusts lasted for 1, 1.5, or 2 s.

In addition, cones were placed at random distances within the drivers' lane. 17 sets of cones appeared in each day of driving; 8 sets in block 1, 9 sets in block 2, 8 sets in block 3, and 9 sets in block 4. The cones were meant to simulate roadway hazards. We would predict that drivers would slow down or make adjustments to their steering in order