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Effects of chronotype and time of day on the vigilance decrement during simulated driving☆

Ángel Correa[a,b,*], Enrique Molina[a,b], Daniel Sanabria[a,b]

[a] Departamento de Psicología Experimental, Universidad de Granada, Granada, Spain
[b] Centro de Investigación Mente, Cerebro y Comportamiento, Universidad de Granada, Granada, Spain

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ABSTRACT

The current study tested for the first time the effect of individual differences in circadian rhythmicity (chronotype) on both driving performance and its evolution along time on task. Morning-type and evening-type female participants were tested in morning (8 am) and evening (8 pm) sessions, in which we controlled for prior sleep duration and prior wake. Measures of body temperature, subjective activation and affect, reaction times (RT) in the Psychomotor Vigilance Task (PVT), behavioral performance (error position) and EEG alpha power during simulated driving were collected. The main result showed strong linear increments of mean and standard deviation of error position along time on task (vigilance decrement) when evening-type participants drove at their non-optimal time of day, that is, during the morning session. In contrast, driving performance in the morning-type group remained stable over time on task and was not affected by time of day. This finding can be due to differences in personality traits (e.g., conscientiousness, sensation seeking) and task appraisal associated to extreme chronotypes. The consideration of chronotype in vigilance and driving tasks can enhance safety and human performance by promoting work schedules and countermeasures to prevent failures in the accomplishment of tasks under non-optimal circadian conditions.

1. Introduction

Performance in vigilant attention tasks after 18 h of extended wakefulness declines until levels equivalent to those produced by the ingestion of the legal maximum amount of alcohol (0.05% blood alcohol concentration) allowed for driving in many countries (Dawson and Reid, 1997). This finding emphasizes the relevance of research on sleep and circadian rhythms in driving. The aim of the current research was to study the influence of several circadian and time-related factors (chronotype, time of day and time on task effects by controlling for prior sleep duration and prior wake) on performance during a simulated driving task.

Circadian rhythms set the timing for basic biological and physiological functions on a daily basis, such as sleeping and feeding, body temperature, hormone production and brain activity, thus influencing behavioral and cognitive functions (Berendes et al., 1960; Kleitman, 1933). Performance in cognitive tasks measuring simple reaction time (RT), attention and vigilance shows circadian rhythmicity, which indicates that the amount of prior wake and the time of day at which a task is accomplished are major influences (reviewed by Blatter and Cajochen, 2007; Lim and Dinges, 2008; Valdez et al., 2010; Wright et al., 2002).

Time of day is a key factor in tasks demanding vigilance such as driving, as highlighted by statistics on traffic accidents (Di Milia et al., 2011; Folkard, 1997). Specifically, traffic accidents occur most frequently when both body temperature and vigilance levels are at minimum, that is, around 3 to 5 am. Time of day effects in driving performance have also been demonstrated by laboratory experiments (Akerstedt et al., 2010; Baulk et al., 2008; Lenné et al., 1997). However, most of these studies have not considered the negative impact that extending duration of prior wake exerts upon driving performance, which can be exacerbated at specific times of day when vigilance is low, for example at 4 am (Matthews et al., 2012).

Individual differences in profiles of circadian rhythmicity, i.e. "chronotype", can be another relevant factor for studies addressing time of day effects on cognitive and driving performance. The chronotype reflects inter-individual differences in the phase (or amplitude) of circadian rhythms, such as body temperature and

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* Corresponding author at: Facultad de Psicología, Campus de Cartuja s/n, Universidad de Granada, 18071 Granada, Spain. Tel.: +34 958247881.
E-mail address: act@ugr.es (Á. Correa).

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sleep cycle (for a recent review see Adan et al., 2012; Kerkhof and Van Dongen, 1996). Morning-type people tend to wake up and to go to sleep earlier, and show more arousal and activity during the morning, than evening-type people. This tendency can be measured by a questionnaire (Horne and Östberg, 1976) and has been related to genetic factors (Katzenberg et al., 1998). Morning-type individuals also show optimal performance on many cognitive tasks in the morning, whereas evening-type individuals show best performance in the evening. This interaction between chronotype and time of day is known as the "synchrony effect" (May and Hasher, 1998).

Chronotype has been acknowledged as a crucial factor in research on fatigue and accident risk (Di Milia et al., 2011). However, the influence of chronotype on driving performance remained to be tested. The few available evidences that measured chronotype have controlled rather than manipulating this factor by testing only participants with intermediate chronotype (e.g., Matthews et al., 2012). A recent study reported that morning-type participants showed higher cortisol levels (indicating higher arousal), reported both less subjective workload and reduced sleepiness than evening-type participants during a simulated driving task (Oginska et al., 2010). Unfortunately, however, the Oginska et al.'s study did not focus on driving performance so that measures related to the driving task were not reported. Therefore, the current study aimed to investigate the influence of chronotype on driving performance, by simultaneously considering time of day and prior wake factors.

Task duration ("time on task") is another relevant factor influencing cognitive performance (Mackworth, 1948), and therefore the level of vigilance during driving. Many studies on real and simulated long driving have reported performance decrements, for example, by showing that the lateral position of the car becomes more variable (i.e., SDlat measure) and less accurate along time on task (e.g., Brookhuis and de Waard, 1993). The time on task effect has been related to increased fatigue and sleepiness, and to decrements in vigilance, which can be indexed by self-report and electroencephalographic (EEG) measures (Otmani et al., 2005; Ranney et al., 1999). For example, subjective sleepiness and EEG alpha activity have been shown to increase concomitantly with time on task (Kecklund and Akerstedt, 1993).

Given that vigilance fluctuates across time of day, it is reasonable to expect that the vigilance decrement during driving can be affected by time of day. This issue was addressed by a recent study, but no interaction between time of day and time on task was reported (Akerstedt et al., 2010). Since chronotype was not measured in this study, it is possible that variability due to individual differences in chronotype might have precluded the finding of clear interaction between time of day and time on task. Hence, the current study tested for the first time (as far as we know), whether the vigilance decrement during driving depends on chronotype and time of day. We have recently found that the vigilance decrement during a task measuring vigilance and response inhibition (the Sustained Attention to Response Task (SART); Robertson et al., 1997) can be prevented by testing morning-type and evening-type individuals at their respective optimal times of day (Lara et al., 2014). Thus, we expected to extend this finding to a simulated driving task, in order to counteract the impairments in performance during long driving.

To summarize, the current study tested morning-type and evening-type participants performing a simulated driving task in morning and evening sessions. Effects of the manipulation of chronotype and time of day were additionally tested by measuring subjective activation (Monk, 1989), vigilance during the Psychomotor Vigilance Task (PVT; Dinges and Powell, 1985), and the slow alpha frequency range of the EEG (Kecklund and Akerstedt, 1993; Klimesch, 1999) before and during simulated driving. These variables were further analyzed by multiple regression (see supplementary material, Section 2.2) in order to model and predict driving performance.

On the basis of the literature reviewed above, we expected to find a reduced vigilance decrement in driving performance when participants were tested at the optimal rather than non-optimal time of day according to their chronotype. We also predicted higher subjective activation, faster RTs in the PVT and lower alpha power in the EEG, at optimal compared to non-optimal times of day.

2. Material and methods

2.1. Participants

Twenty-nine participants with extreme chronotype were contacted from a database of students from the University of Granada who completed the Spanish reduced version of the Morningness–Eveningness Questionnaire (Adan and Almirall, 1991) to take part in the experiment voluntarily. Data from four participants were excluded from the study as they either crashed the car (two of them were driving at their non-optimal time of day) or missed one session. Data from eleven participants who either slept less than 6 h the night prior to the experiment, did not complete any of the tasks or their EEG recording was excessively noisy, were replaced by testing new participants.

Summing up, data from 25 participants (age range 18–26 years old, mean age = 21.09, SD = 2.46), all of them female, right-handed, with normal or corrected to normal vision, were finally included in the analyses. Testing only females was not particularly intended and was due to practical reasons regarding higher availability of this specific sample. There were no male participants in the rejected sample described above. Thirteen participants with scores of 17 and above were assigned to the morning-type group, whereas 12 participants with scores of 9 and below were assigned to the evening-type group. The study was conducted in accordance with both the ethical guidelines of the University of Granada and the standards laid down in the 1964 Declaration of Helsinki. Participants gave informed written consent before the study and they were rewarded with course credits for their participation.

2.2. Apparatus and stimuli

Participants' body temperature was measured by means of an electronic thermometer placed under the armpit. The reduced version of the Spanish adaptation of the Morningness–Eveningness Questionnaire (rMEQ, Adan and Almirall, 1991; Horne and Östberg, 1976) was developed to measure participants' chronotype on the internet (available at http://wdb.ugr.es/ molinae/rmeq/). Scores in this questionnaire can range in a continuous between 4 (extreme eveningness) and 25 (extreme morningness). Subjective activation and affect were measured by an electronic version of the Visual Analog Scale developed by Monk (1989). Scores can range from 0 (minimum activation/positive mood) to 100 (maximum activation/positive mood).

The simulated driving task and the PVT were run on the same PC laptop (Intel Core 2 Duo at 18 GHz with 2 GB of RAM, 15.6″ LCD screen). The PVT task was programmed with E-Prime software (Schneider et al., 2001). The target stimulus was a black circle with a red edge (diameter: 9.15° of visual angle at a viewing distance of 50 cm). As simulated driving task we used the Racer software (http://www.racer.nl/; version 0.89), which is free, customizable through ASCII files and it generates a log file on driving performance that can be analyzed with Matlab (Mathworks Inc.).

The track used in our study was the Speedest2 (http://www.racer-xtreme.com/), a road forming a big ovaled-rectangle (approximately 3000 m × 1750 m, with a bend radius of 850 m),