Accident Analysis and Prevention 41 (2009) 763–771

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Mental workload when driving in a simulator: Effects of age and driving complexity

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ARTICLE INFO

Article history:
Received 3 December 2008
Received in revised form 12 March 2009
Accepted 23 March 2009

Keywords:
Driving
Aging
Simulator
Mental workload
Intersections

ABSTRACT

Driving errors for older drivers may result from a higher momentary mental workload resulting from complex driving situations, such as intersections. The present study examined if the mental workload of young and older active drivers vary with the difficulty of the driving context. We adopted the probe reaction time (RT) technique to measure the workload while driving in a simulator. The technique provided clear instructions about the primary (driving) and secondary (RT) tasks. To avoid structural interference, the secondary task consisted of responding as rapidly as possible with a vocal response ("top") to an auditory stimulus. Participants drove through a continuous 26.4-km scenario including rural and urban sections and probes (stimuli) were given in a baseline static condition and in three different driving contexts embedded into the overall driving scenario. Specifically, stimuli were given randomly when (a) driving on straight roads at a constant speed, (b) approaching intersections for which the driver had to stop the car, and (c) when overtaking a slower vehicle. Unless a driving error was made, drivers did not need any emergency responses. Reaction time was defined as the temporal interval between the auditory stimulus and the onset of the corresponding verbal response detected from the analog signal of a piezo-electric microphone fixed on a headset (ms accuracy). Baseline RTs were similar for both groups. Both groups showed longer RTs when driving and RTs increased as the complexity of the driving contexts increased (driving straights, intersections, overtaking maneuvers). Compared to younger drivers, however, older drivers showed longer RTs for all driving contexts and the most complex driving context (overtaking maneuvers) yielded a disproportionate increase. In conclusion, driving leads to a greater mental workload for the older drivers than for the younger drivers and this effect was exacerbated by the more complex driving context (overtaking maneuvers).

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1. Introduction

The act of driving offers mobility and independence. These characteristics are not only practical, but also symbolic, particularly for older drivers. Currently, in most western countries older drivers represent about 12–15% of the driving population and they are the fastest growing segment of the driving population. For instance, in Canada, drivers older than 65 years represent 13.2% of the total population of licensed drivers and it is expected that within the next 15–20 years, they will represent about 25% of the driving population (Robertson and Vanlaar, 2008). Driving is a perceptual-motor skill, these can be closed or open skills. As opposed to being a closed skill for which the environment is predictable and relatively stable, driving is an open skill with a dynamic environment. Success in open skills is often determined by the extent to which an individual is successful at adapting behaviors to the changing environment and the complexity corresponding to the context (Schmidt and Lee, 2005). There are several reports suggesting that older drivers may have difficulty in adjusting their driving behaviors to complex traffic situations which require adaptations. For instance, in a recent review of collision situations involving older drivers, Mayhew et al. (2006) reported that compared with younger drivers, older drivers are overrepresented in overtaking another vehicle and merging crashes, angle crashes and intersection crashes. Similar data have been presented elsewhere (Langford and Koppel, 2006; McGwin and Brown, 1999; Oxley et al., 2006). The reasons for these over representations are not clearly understood.

Several retrospective analyses of crashes suggest that, compared to younger drivers, older drivers violate more traffic controls (Preusser et al., 1998), fail to yield the right of way and to heed stop signs or signals (McGwin and Brown, 1999). Braitman et al. (2007) recently conducted phone interviews of 227 older

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0001-4575/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2009.03.019

drivers involved in non-fatal intersection crashes. The authors mentioned that drivers aged 70–79 reported more misjudgments about whether there was enough time to proceed whereas for older drivers (80+) search errors (e.g., looking but not seeing) were more predominant as the potential cause of the accident. These studies, although they provide valuable information about crashes, are not without limitations since they often rely on a subject's recollection of events and this may not correlate with actual information processing activities preceding the events (and the driving error).

As errors are often the consequence of high mental workload, there is a large body of literature on the topic of mental workload. When driving, measuring the mental workload can provide an indication of the cognitive demands placed on the driver (de Waard, 1996; de Waard and Brookhuis, 1997). There are several techniques available to measure their mental workload. This includes subjective opinions, physiological measures and task performance. It is beyond the scope of this paper to review all issues related to mental workload measurements (for a review, see Tsang and Wilson, 1997). The measurement technique adopted for the present study uses a secondary subsidiary task; drivers are instructed to maintain driving performance (primary task) and to respond as rapidly as possible to an auditory stimulus (secondary task). This method seeks to saturate a presumed limited mental workload capacity, that is a single-channel operation for performing mental tasks and thus attempts to estimate the proportion of this channel that is necessary for successful completion of the primary task (Kahneman, 1973; O'Donnell and Cohen, 1993). To measure the workload imposed by the primary task, we compared the levels of performance obtained when the secondary (or loading) task is performed alone (RT task in the present study) with the performance obtained on the same task when it is performed simultaneously with the primary task (driving in the present study). The purpose of the secondary task is not to perturb the primary task (driving) but to quantify the workload imposed by various levels of driving complexity through changes in performance of the secondary task. For instance, Hancock et al. (1990) used this technique to examine the mental workload for left and right turn maneuvers compared to driving straights (on-road measurements) by asking subjects to respond to a probe light mounted on the dashboard directly in front of them. Drivers were asked to press a button as rapidly as possible after detection without modifying their driving performance. Response times were longer during turn maneuvers than when driving straights; this suggests that a higher driver workload characterizes turn sequences compared to driving straights. Although these results are valuable, there is a possibility that the motor action (i.e., pressing a button) was delayed because it interfered with steering control when turning. More recently, several authors have adopted a variation of this technique, the peripheral detection task or PDT (Jahn et al., 2005; Patten et al., 2006; Verwey, 2000) to quantify mental workload for various driving contexts. Generally, results show that PDT response times and errors increase with the complexity of the driving contexts. As an example, Jahn et al. (2005) reported that driving within a city center (with complex intersections and road signs where the driver has to yield the right of way) resulted in longer PDT response times than driving in urban and rural areas characterized by reduced interactions with other vehicles. Patten et al. (2006) reported similar observations. In addition, these authors showed that, compared to a group of more experienced and active drivers, less active and experienced drivers were slower to respond to the PDT. These results are important because they highlight that driving is not an automated task and that the workload generally increases with an increased complexity of the driving context and with a lack of expertise. There are few data available on mental workload when driving in a simulator particularly so for older drivers. One example of such work is that of Verwey (2000). In this experiment, young and older drivers performed a visual detection task or a simple addition task (with the information presented auditory) when driving on-road. Older drivers were less accurate than younger drivers with the addition task when driving in roundabouts and highways. It is worth nothing that no age effects were documented for the visual detection task. However, for the other driving contexts (e.g., straight roads, turning right or left at uncontrolled intersections), older drivers showed a reduced performance but the difference was not statistically significant. A better understanding of the workload imposed by various driving conditions would therefore help to understand the etiology of driving errors in older drivers (and young or novice drivers). There is a possibility that, for older drivers, an increased mental workload during more complex maneuvers could reduce their ability to switch their attention between critical tasks (e.g., watching coming traffic, pedestrians, reading traffic signs, dashboard displays) (Rizzo et al., 2004). To verify how mental workload varies within a simulator environment, we designed an experiment where driving was the primary task and responding to an auditory stimulus with a verbal response was the secondary task. The following hypotheses were tested: (1) as for on-road driving, more complex driving maneuvers impose a greater mental workload on the driver, (2) all driving contexts impose a greater mental workload on older than on younger drivers, and (3) compared to younger drivers, more complex driving contexts impose a greater mental workload on older drivers.

Table 1
Descriptive results for the young and elderly drivers ($N = 10$ for each group).

	Young drivers	Elderly drivers	*p* values
Age	24.0 (3.5)	69.4 (3.0)	<0.001
Years of driving experience	7.0 (2.4)	47.5 (5.3)	<0.001
Alcohol consumption per week	3.4 (3.9)	3.1 (3.8)	>0.05
MMSE	28.0 (1.2)	27.2 (0.4)	>0.05
Snellen high contrast	0.9 (0.3)	1.0 (0.2)	>0.05
Snellen low contrast	1.2 (0.4)	1.6 (0.6)	>0.05
Melbourne edge test	21.7 (1.5)	19.3 (1.3)	<0.01

2. Method

2.1. Participants

Ten young (mean age = 24 years, range = 20–31) and ten older drivers (mean age = 69 years, range = 65–75) participated in the study. Older drivers were recruited by advertisements in local newspapers and through aging coalitions. Younger drivers were recruited from the academic community of Laval University. All subjects were males to avoid gender effects. Upon their arrival in the laboratory, each participant was briefed on the requirements of the experiment and all read and signed an informed consent declaration that conformed to Laval University Institutional Review Board policy. Subjects completed clinical tests (MMSE (Folstein et al., 1975), Snellen visual acuity, Melbourne edge test (Verbaken, 1989)) and a general verbal questionnaire which included items on driving history (years of driving experience, frequency of driving and average km/week and year) and general health (neurological and musculoskeletal problems, use of medication, drinking habits). There is a currently a debate regarding the validity of self-reports to estimate driving exposure (Langford et al., 2006; Staplin et al., 2008). The questionnaire information only served to verify that participants were "active" drivers and not to establish a "low mileage bias". All subjects scored 27 or higher on the MMSE and had normal or corrected to normal vision. Table 1 presents a summary of these observations.

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