

The quantity and nature of in-vehicle cognitive demands experienced by real-world drivers

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Abstract: A real-world driving study was conducted into the cognitive demands within the cabin of a modern domestic car. The quantity and nature of the interactions were recorded, along with dashboard and centre console glances. Ethnographic data was collected from a sample of 8 drivers using remote video analysis and a journey diary. The results suggest that glancing at the dashboard is the highest singularly demanding task, and the highest cognitive demands occur when several types of visuospatial sketchpad representational information are presented to the driver. Therefore, the type of information presented may be more demanding than the area it comes from.

Keywords. Vehicle Ergonomics, Cognitive demands, Design ethnography, In-vehicle

1. Introduction

The development of recent technologies has meant an increase in the presentation and amount of features within today's modern vehicle. More and more features are being introduced into the vehicle to aid interaction between the driver and the vehicle, and/or the driver and the external environment. However, the consequence of the increase in features and thus interactions are currently unknown. A key cognitive consideration within this is Millers 1956 theory on the working memory- the constant capacity hypothesis of 7 ± 2 chunks of information at any one time (Miller, 1956). Cowen et al (2004) counter argued this with a constant-capacity hypothesis in the range of three to five chunks (Cowan, Chen, & Rouder, 2004).

The effect of increased features on the working memory and other cognitive loads is currently unknown and requires further investigation. This is a major road safety implication considering the highest cause for reported accidents in the UK was due to driver error which amounted to 44% of reported accidents in 2013 (Department for transport, 2013). Driver error (or human error) can be split into skill based errors, decision errors and/or perceptual errors (Reason, Manstead, Stradling, Blaxter, & Campbell, 1990). Each of these error categories use descriptions such as 'wrong response', 'exceeded ability' and 'misjudged' (Shappell, 2000) which indicate cognitive loading may be a contributory cause of the error. However, it is important to separate the environmental and situational (outside the vehicle) demands and in-vehicle (inside the vehicle) demands.

This paper aims to initially highlight the demanding in-vehicle tasks through analysis of what people actually do when they drive on UK roads. Upon establishing trends and reoccurring demands it will then be possible to quantify these demands and determine the cognitive loads experienced in a modern domestic car. The objective of this study was to capture natural behaviour in the real world to reflect day- to- day driving scenarios.

2. Methods

To obtain the most naturalistic behaviour possible, a mixed- method ethnographic

approach was adopted, utilising both remote video analysis and diary studies as data capture methods. This approach offered the greatest insight into the driver's natural behaviour and habits, and allowed qualitative data to be collected and analysed.

Ethnography allowed for a naturalistic insight into the real-world interactions between the vehicle and the driver through overt observation. The vehicles selected for the study were equipped with video recording equipment and a journey diary for a duration of 48 hours. This allowed enough time for the users to feel comfortable with video recording equipment in their vehicle. Thus, potentially leading to drivers adopting as naturalistic behaviour as is possible. Two cameras were positioned to capture the driver's eyes, hands, the dashboard and the centre console to establish what they interacted and glanced at, as well as revealing interesting habits, actions and behaviours. The cameras did not capture any sound to allow the data to be analysed objectively on playback plus it reassured the driver that their privacy was respected. Drivers did not carry passengers in the front seat.

The journey diary was used to offer insight into the participants' journey destination, time of travel and familiarity of the journey as well as more personal information about their prior sleep and food and drink consumption. This method combined with the video analysis, allowed a thorough ethnographic insight into the driver's behaviour and habits and more importantly why that behaviour may be apparent. Each participant was requested to fill out the journey diary after each journey or where possible that contains information on the variables and surroundings of each of the journeys they took. The diary allows the participant to document any alerts or distractions the vehicle has demanded from them. The diary also gave the participants a platform to suggest feedback and improvement to be made to the study.

2.1 Sample

Participants were selected based on the following three variables: 1) vehicle type, 2) vehicle age, and 3) driver age. Vehicles less than 6 years old were all considered for the study (manufactured between 2009- 2015) and a random sampling method was used to include a varied age range of participants. The study sample used for discussion in this paper is 8 participants ($n=8$), aged between 24- 58 years old (average age = 43 years). The sample included 5 male and 3 female participants. Each participant drove their own car for the purposes of the study in order to reflect typical naturalistic driving behaviour. Participants had been driving that particular model of car for an average of 2.6 years and had been driving for an average 25 years in total. Each participant was given an information sheet and signed a consent form prior to completing the study.

2.2 Equipment

The equipment used in each vehicle were 2 x 'full high definition 1080dpi dashboard cameras', 2 x '3 meter USB to mini USB cables' attached to a '4 port USB to 12 volt battery charger' that attached to the 12 volt battery socket (cigarette lighter) inside the vehicle. One of the cameras was positioned under the passenger headrest inside a case, with the lens pointing towards the driver (Camera 1). The other camera was in the top left hand corner of the windscreen pointing towards the driver (Camera 2). Due to the wide-angle lens on both cameras, the footage records the driver's eye movements, what they touch and any other behaviours or habits in the vehicle. The equipment took approximately 10 minutes to install and allowed enough time for the participant to read the information sheet, sign the consent form and resource return form. Following the installation of the equipment, the participant was asked to go about their daily journeys as normal and that there was no need to interact with the cameras. They were then issued with a journey diary which was briefly explained to them. The participants were asked to return the equipment upon completion of the 48 hours study.

2.3 Data Analysis

Upon completion of the study, the data from the diary and the cameras was collated and ordered. A random sample of 30 minutes including at least two journeys was taken of each participant for analysis to allow for naturalistic driving behaviour. Data analysis was conducted in two stages, stage one analysis was taken from the raw data which then informed the results of stage two analysis.

Video footage was analysed using Kinovea (computer software), which allowed the footage from both camera 1 and 2 to be played and paused simultaneously. The journey diary information was transcribed onto a Microsoft Excel spreadsheet and used to align the correct videos to the corresponding journey. To analyse the videos, each time a glance or interaction was made, the videos were paused simultaneously (with one button through the Kinovea software) and the glance or interaction was noted on the same Microsoft Excel spreadsheet against task headings. A glance was counted anytime the participants gaze was taken off the road through the front windscreen at any point and an interaction was counted any time hands moved from the wheel or their resting position. For stage one analysis of the data each glance or interaction was marked down against several task headings. These were split into dashboard glances, dashboard interactions, and centre console glances, centre console interactions, driving habit glances, and driving habit interactions. Under each of these headings included a large list of tasks. Tasks were added to the spreadsheet if they were observed in the analysis, but missed off the initial list of tasks. On completion of analysis of 8 participants recording sample, totals, percentages and averages were calculated from the results.

The averages taken from the stage one analysis (above) were used in a cross analysis of two categories (stage two). The first category identified the working memory cognitive system and the second identified the type of information.

The working memory has often been split into verbal and visual thinking systems with the definition of each system changing between theorists. The stage two analysis framework used Baddeley's theory of the working memory as it is the most widely cited theory that has been continuously developed since 1974. According to Baddeley's theory, the working memory is split into the Phonological loop: used for auditory functions including spoken words and music, and the Visuospatial Sketchpad: used for Visual functions including writing and pictures. These two systems are both dependant on a third attention-limited control system called the central executive (Baddeley, 2003).

Information displays can often be categorised into static or dynamic, but a more detailed human factors task classification system is split into 8 categories. These include:
Quantitative information: Displays with precise variable value (speed, temperature),
Qualitative information: Displays indication of a changeable variable (pressure rising),
Status information: System status conditions (on- off indications, stop- caution- go),
Warning and signal information: Indicate emergency situations (objects or conditions),
Representational information: Pictorial or graphic representations (interactive interfaces),
Identification information: Identify situations or conditions (hazards, traffic lanes),
Alphanumeric and symbolic information: Symbolic static information (instructions, labels),
Time phased information: Display presentations of pulsed or time phased displays (blinker lights, Indicators) (Sanders & McCormick, 1992).

3. Results

3.1 Journey diary results

The results of the journey diary showed that the average amount of journeys between 8 participants made in 48 hours were 7, with an overall average journey time of 26.04

minutes. The average amount of journeys made in the daytime were 91% and 30% of those journeys were made in rush hour (8am- 9am, 5pm-6pm). 88% of journeys made over 48 hours were familiar journeys and 54% of journeys were in urban settings.

3.2 Stage one video analysis results

Ethnographic video analysis results were quantified and showed the 5 largest demands (most frequently occurring) were the dashboard glances (average = 31 glances), interaction with face/ hair/ glasses/ nails (average = 25.62), multimedia centre low interaction (average = 18.33^r), multimedia centre middle interaction (average = 15) and indicators (average = 14.37). These demands are shown in figure 1 along with other demands that were recorded. The tasks shown in figure 1 are a combination of tasks demanded by the driver from the car (e.g. multimedia centre interactions), by the car or environment from the driver (e.g. indicators), and several non-driving related tasks (e.g. glance at phone). The interactions and glances with the mirror were disregarded as they could be considered as environmental or situational demands rather than in-vehicle driving demands. However, the frequency of these demands proved to be two of the highest; the rear view mirror glances (average = 29.75) and the side mirror glances (average = 28.25).

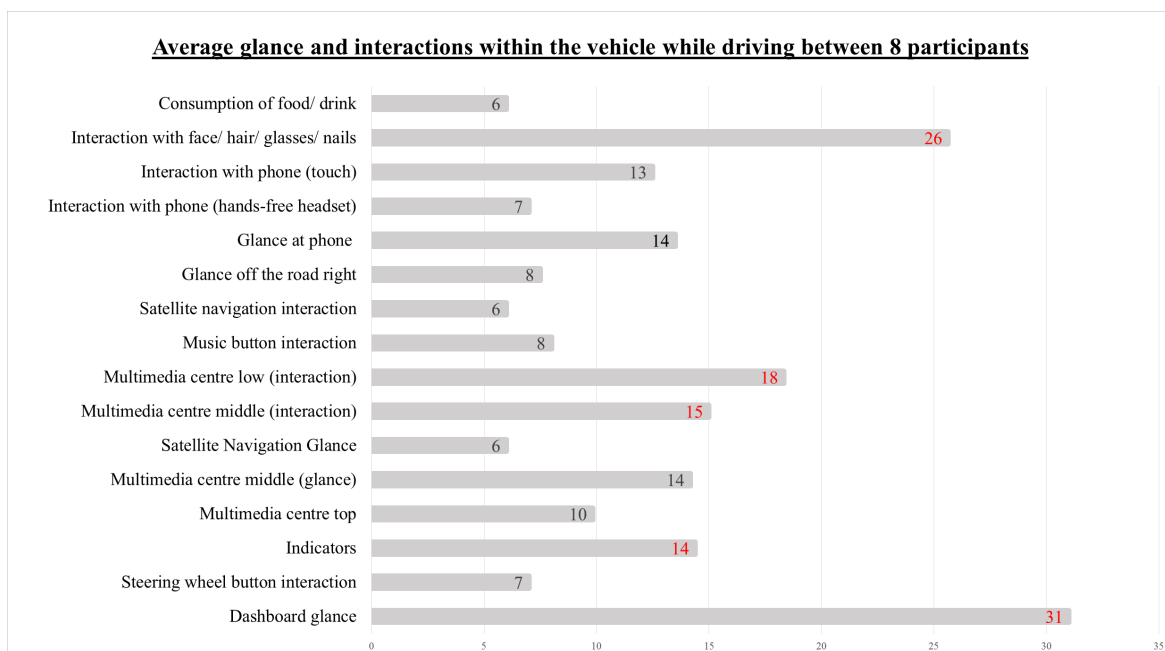


Figure 1: A bar chart to show the rounded average driving glances and interactions taken from a 30 minute sample of 8 participants over 48 hours.

The most demanding task category overall was the driving habit interactions (total = 294), dashboard glance (total = 262), centre console interaction (total = 238), centre console glance (total = 199), dashboard interaction (total = 191) and the least demanding task category was the driving habits glance (total = 139). This means that overall, the most demanding task category for both glances and interactions was the dashboard (overall total = 453). This was followed by centre console (overall total = 437) and driving features (overall total = 433). There was another total that was excluded from these groups which was the mirror glance total (overall total = 464) meaning this was higher than the most demanding area of the vehicle highlighted above. The least demanding tasks observed from this study included steering wheel glance (average = 2.8), multimedia centre interaction top (average = 2.33) and hands-free telephone call through the centre console (average = 3).

Many other tasks had a low interaction or glance average including interaction with food or drink (average = 2.5), air con glance (average = 2.33r) and changing cd (average = 2).

3.3 Stage two analysis results

The results shown from the task categories and cognitive function cross analysis (see table 1) suggests that the largest total distractions was classified as visuospatial sketchpad representational information (total average value = 45.46), [such as steering wheel button interaction, and multimedia centre interaction]. Stage two analysis points out other particularly demanding areas as visuospatial sketchpad alphanumeric information (total average value = 37.66) [such as glances towards air conditioning, multimedia centre and mobile phones], visuospatial sketchpad quantitative information (total average value = 32) [such as dashboard glances] and phonological loop representational information (total average value = 24.5) [such as interaction with phone via touch and voice] (see Figure 2).

Average of participants glances and interactions completed while driving a vehicle over a 30 minute sample of a 48 hour study.









								
	Quantitative:	Qualitative:	Status info:	Warning & signals	Representational:	Identification:	Alphanumeric:	Time Phased:
Visuospatial sketchpad Visual system processing written material or pictures	Dashboard Glance 31	Air con Int 4	Sat Nav Glance 6	Air con Int 4	Steering wheel Glance 2.8	Rear Mirror Glance 29.75	Air con Glance 2.5	Lights interaction 1
	Dashboard Int 1	Mirror Int 1.5	Sat nav Int 6		Steering wheel Int 7	Side Mirror Glance 28.25	Multimedia top Glance 10	Wiper interaction 4.75
		Window button Int 3.33			Multimedia Int top 2.33	Right of wheel Int 1	Multimedia middle Glance 14.16	Indicator interaction 14.37
					Multimedia Int Middle 15	Glance off road down 6.5	Multimedia low glance 4.5	
					Multimedia Int Low 18.33	Glance off road right 7.5	Glance at watch 2	
						Glance off road Left 4.25	Glance at phone 13.5	
						Glance off road into car 5		
Total =	32	8.83	12	4	45.46	24.25*	37.66	20.12
Both		Interaction with another person 3.66			Int with phone (Touch) 12.5			
Phonological Loop Auditory system processing spoken Words and music		Reversing camera 3.33	Hands free call 2		Phone interaction voice 1	Sat nav voice activation 1	Music button Int 8	
					Phone interaction (Hands-free headset) 7		Changes CD Interaction 2	
					Incoming call via Media centre 4		More than 1 button Int 2	
					Interaction with phone (Touch) 12.5			
Total =		3.33	2		24.5	1	12	
Other cognitive function		Interaction with face/hair/glasses/teeth 17.37				Int in the car 1.8		
		Rearranges seatbelt/clothes 2.5				Interaction with food/drink 2.5		
		Hand on leg/vest/arm rest 4.33				Consumption of food/drink 6		
		Changes driving Position 1						
Total =		25.2				10.3		

Figure 2: Stage two analysis table plotting task averages against information and cognitive categories.

Upon inclusion of rear-view and side mirror data, the results suggest the visuospatial sketchpad identification information (total average value = 82.25) would be the most demanding area of the vehicle (the mirror data has been disregarded, see above). Several findings did not fit into either category and two average tasks appear to use both visuospatial sketchpad and phonological loop (see Figure 2).

4. Discussion and Conclusion

4.1 Discussion

Interestingly, the highest average task performed while driving was a dashboard glance at 31 average glances over a 30 minute period. Also, the most demanding task category

was the dashboard (overall total = 453). However, after stage 2 analysis of all tasks, the dashboard tasks came under the visuospatial sketchpad quantitative information which was only ranked as the 3rd most demanding information category as suggested by stage two analysis. These findings indicate that although the most singular demanding area may appear to be the dashboard, the combination of multiple tasks indicates that several of the same type of demands may affect cognitive loading more, especially visuospatial sketchpad system cognitive loading. Another example of this is the centre console; the tasks performed under these section headings (such as multimedia, air con, satellite navigation glances and interactions) as a total were the second highest demanding area of the vehicle. However, when the tasks are split into their information type (such as symbolic static information [alphanumeric] or status information displays) and visuospatial sketchpad (visual) or phonological loop (verbal) the results are completely different. Therefore the type of information being presented to the driver may be more loading than the area it comes from.

The qualitative insights revealed from the ethnographic study suggested a possible correlation between the amount of interactions and journeys where the participants had below the average recorded (6-8 hours) amount of sleep. The analysis suggested that when some participants were tired, their interaction rate with indicators (i.e. not indicating when turning corners) and the centre console was lower than when the same participants had an average amount of sleep.

4.2 Conclusion

The most demanding individual task was dashboard glance (total = 31). Driving habit interactions were surprisingly the highest demanding task type (total = 294) which was largely due to interactions with face/ hair/ glasses/ nails (total = 205) which was under this section title. This research extends our knowledge of demanding areas within the vehicle and suggests an enhanced understanding of the most demanding information type (representational) and the cognitive system used to process this information (visuospatial sketchpad). The research suggests that the type of information being presented to the driver may be more cognitively demanding than the area within the vehicle presenting that information, which could have significant implications on road safety overall.

The total number of participants needed to allow for a reliable representation of the wider population is 32 people (based on a mean of similar studies data sets and to allow for repeats of comparable driving conditions). Data from 24 further participants will be analysed to build on the conclusion from the current data and rule out any anomalies or outliers. The data gathered from these 8 participants will form the basis for the next stage of research that will look to analyse this area with more data. Future studies will be looking to quantify the cognitive loading that is suggested from stage two analysis and to establish how these tasks can be improved to minimise cognitive load.

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