Measuring Cognitive Workload of Novice Law Enforcement Officers in a Naturalistic Driving Study

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There is a large amount of variation between novices and experts in their cognitive workload when performing tasks. A naturalistic pilot study was conducted with nine novice law enforcement officers (nLEOs) to determine how their use of in-vehicle technology affected their cognitive workload during their normal patrols. Physiological data were collected using a novel synchronization process for naturalistic driving studies, allowing heart rate variability and eye tracking measurements to be synchronized together and directly compared to subjective workload levels. It was found that nLEOs have average or higher workload compared to experienced officers and the general population when they are on duty. Future studies can utilize the approaches and findings of this pilot study for conducting naturalistic driving studies and developing cognitive performance models for novice users.

INTRODUCTION

Cognitive workload (CW) can be defined as "the relation between the function describing mental resources demanded by a task and those resources available to be supplied by the human operator" (Parasuraman et al., 2008, pp. 145-146). CW can vary greatly on a similar task when performed by novices compared to experts. Novices tend to look through many chunks of data to find what they need while experts are able to filter information and search specific chunks more quickly (Carmichael et al., 2010; Sharif et al., 2012). The frequency of saccades and fixations for novices are higher than experts and it takes more time for novices to detect anomalies than experts (Kundel & Nodine, 1975). Concerning memory, experts have advantages in chunking ability (Kavakli & Gero, 2003), the amount of information in long-term memory (Sohn & Doane, 2003), and memory decaying speed (Estes, 2015). In motor aspects, novices have longer reaction times as compared to experts (Hick, 1952; Hyman, 1953).

CW of novice drivers is significantly correlated with their reduced task performance in high-demand driving conditions (Drummond, 1989). For example, novices scan more frequently for hazards on the roads (Underwood, 2007) and must put conscious effort into their steering and speed control to avoid road hazards unlike experts that can adjust to and avoid hazards with muscle memory. Novices also lack schema, experiences, and relevant rules of behaviors to effectively complete their task (Borowsky et al., 2008). In addition, they have inadequate situation awareness (McKenna & Crick, 1994). For example, while driving, novices exhibited shorter glances and responded less quickly on the phone as compared to experts (Smiley et al., 2007). While these examples are for drivers in general, the patterns in task performance can be applied to novices and nLEOs as well.

Police operations are examples of high-demand driving conditions. Based on the previous studies (e.g., Zahabi et al., 2021), we can assume that novice law enforcement officers' (nLEO) task performance can be reduced due to high CW. Prior studies have found officers' use of in-vehicle technologies while driving (Yageret al., 2015), fatigue (Vila & Kenney, 2002), and lack of sufficient training in handling high-demand situations (e.g., pursuit situations, multi-tasking) (Hembroff et al., 2018) are major contributors of motor vehicle crashes for LEOs. In addition, LEOs are continuously surrounded by the high noise level inside the police vehicles which can lead to poor speech recognition, and complexity of tasks which can interrupt their concentration on tasks and ultimately increase their CW (Miller & Kun, 2013; Shahini et al., 2020).

Current approaches to measure cognitive workload

CW measurement techniques are typically categorized into four groups including: physiological measures, subjective rating scales, task performance measures (Eggemeier & Wilson, 1991), and cognitive performance modeling (CPM). Physiological measures can directly and continuously measure CW based on the changes in pupillometry data (Zahabi et al., 2022), heart rate (HR) (McDonald et al., 2019), respiratory rate (RR) (McDonald et al., 2019), and skin conductance (SC) (Singh et al., 2013). CW can also be measured subjectively by measures such as the NASA Task Load Index (NASA-TLX) (Hart, 1986) or objectively using task performance responses such as task completion time (Shahini et al., 2021). Lastly, CPM can be a predictive tool to assess CW by using measures such as the number of cognitive operators or working memory chunks required in a task (Zahabi & Kaber, 2018b).

Research gaps and objectives

Prior studies on measuring CW of law enforcement officers (LEO) were conducted in laboratory settings and focused on experts (Zahabi & Kaber, 2018a, 2018b; Zahabi et al., 2019). However, due to the differences in cognitive processes between novice and experts, those results might not be generalizable to novice law enforcement officers (nLEO). Therefore, this study is focused on measuring nLEOs' CW during their regular work shifts and using non-obtrusive wearable devices to collect physiological measures.

METHOD

This study was carried out by conducting a naturalistic driving study with nine police officers. Each participant was observed for a period of at least three hours and their physiological data were collected to determine how their CW was affected by the use of in-vehicle technology. The study protocol was approved by the institutional review board (IRB). All participants were treated according to the American Psychological Association's (APA) ethical research guidelines. In the following sections, we describe the participant demographic information, apparatus, study procedure, data synchronization, and analysis approaches.

Participants

Eight male and one female nLEOs were recruited for this study (Age: *M*= 29.1 yrs., *SD*= 5.73 yrs.). All officers were novices as they had fewer than five years of experience as a primary patrol officer (Hillerbrand, 1989). The study was conducted during officers' regular work shifts during mornings and afternoons, as the eye tracking equipment did not function in the dark. Weather during these ride-alongs ranged from sunny to overcast to rainy.

Apparatus

Three devices were used to record various physiological measurements as well as the video data. To record HR variability (HRV) and galvanic skin response (GSR), participants wore the Empatica E4 (Empatica) watch on their wrist. Eye tracking data including blink rate, pupil size, and the proportion of time spent fixated on various areas of interest (AOIs) were captured using Pupil Labs eye-tracking glasses. The AOIs consisted of the front windshield of the car and any in-vehicle technology/display the participant had in their vehicle, such as the mobile computer terminals (MCTs), dashboard, control panel, etc. A dash camera was attached to the roof of the vehicle to observe the officer's interactions with their in-vehicle technology. These devices and the metrics they recorded are outlined in Figure 1. Figure 2 illustrates the view of the dash camera when installed in the officer's vehicle.

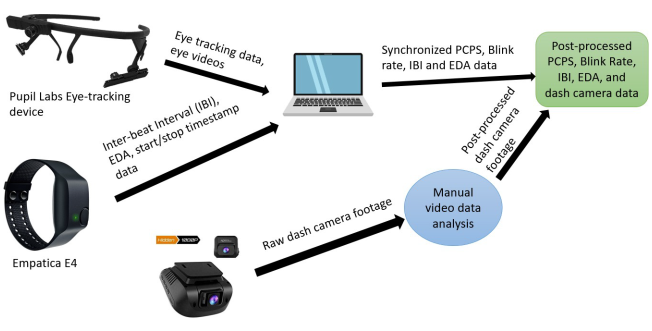

Figure 1: Outline of data collection devices for this pilot study.

Data synchronization

A specific procedure was followed every time data collection was started and stopped to ensure that the raw data collected from all three devices could be attributed to the same time frame. This procedure revolved around use of a feature of the Empatica E4 that allows the user to take timestamps during recordings by pressing a button on the watch. To allow the data to be synchronized in post processing, a timestamp was taken shortly after all three devices had been calibrated and started recording. This timestamp was taken in view of the dash camera and everything that happened before this timestamp was taken was ignored in post-processing.

For the eye tracking and heartrate data, the timestamps were used in a code created in R (version 4.1.1) that removed any data points that occurred before the timestamp was taken. This process of taking a timestamp was repeated any time the experiment had to be paused when the participant exited their vehicle and every time the experiment resumed. Through this process, the data could be reliably synchronized despite different recording devices being used.

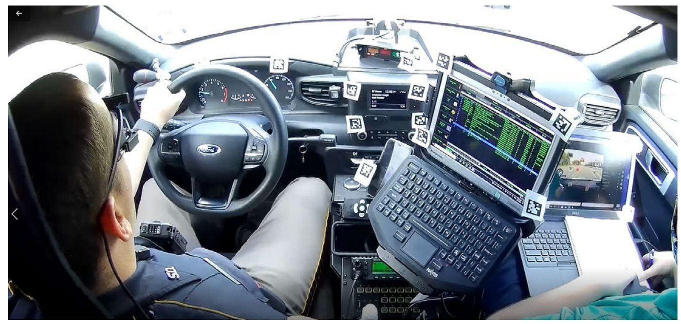

Figure 2: View of dash camera in police vehicle.

Procedure

The study began with participants filling out an informed consent form and a demographic questionnaire. Once these forms were filled out, they were given the E4 to wear and instructed to wear it for at least 15 minutes to allow it to calibrate while the eye tracking and dash camera equipment was set up in their car. Once both of these conditions were met, the eye tracking device was calibrated and the observation period could begin. The synchronization procedure was carried out as detailed in the previous section to allow the observation to start. Once the observation period had begun, the researcher was responsible for monitoring the status of the equipment from the passengers-seat and ensuring that data collection continued smoothly. They were also in charge of carrying out the synchronization procedure whenever the participant had to stop the vehicle for a traffic stop or any similar situation requiring the participant to leave their vehicle.

After the data collection, the participant filled out a driver activity load index (DALI) to subjectively measure their CW for that specific shift while the equipment was removed from their vehicle. The participant was then provided with a copy of the informed consent form for their reference and thanked for their time.

Data analysis

Data analysis for this pilot study was broken down into two groups. The physiological results were grouped and analyzed individually while the video data from the dash camera were reviewed for instances of interaction with in-vehicle technology to determine potential sources of high CW. Combining these two post-processing procedures yielded a clearer idea of how affected participants were by the use of their in-vehicle technology in terms of CW. The participants' responses to the DALI were also considered as implications for how aware participants were of their own

CW during their jobs. For the physiological measures of CW, root mean squared standard deviation (RMSSD) as a measure of HRV, GSR, PCPS, and blink rate were measured in synchronized 5-minute intervals. This interval was chosen because 5 minutes is the standard interval used for collecting accurate RMSSD measurements (Electrophysiology, 1996). Calculating RMSSD involved finding the square root of the mean of the difference between subsequent inter-beat-interval values squared.

Blink rate was calculated first in one-minute intervals. The number of blinks found in each minute was counted and used as the blink rate for that minute. Each 5-minute interval blink rate was then found by averaging the five one-minute interval blink rates within it. Calculating PCPS first involved taking baseline readings of participants' eyes before and after data collection. In post processing, the average pupil diameter from these baselines was subtracted from the average pupil diameter of each recorded 5-minute interval. This result was then divided by the baseline value and multiplied by 100 to obtain the PCPS for that 5-minute interval. The frequency that each officer looked at each AOI was also measured as an indicator of which in-vehicle technologies were used most often by participants.

RESULTS

Physiological data

Due to the fact that this investigation was a pilot study and the data were collected from nine officers in the field, we provided the descriptive statistics on the collected measures as shown in Table 1. The GSR data was not captured from participant 2 due to a data collection error with the E4 which might have been caused by the officer jostling the E4 device when getting in or out of their vehicle while patrolling.

Table 1: Descriptive statistics from the pilot study

Participant	GSR (uS)	RMSSD	PCPS (%)	Blink Rate (/min)	DALI (0-5)
1	0.29	0.12	12	5.57	0.53
2	N/A	0.08	26	19.62	0
3	0.29	0.09	-2	8.84	1.27
4	2.46	0.07	7	8.68	2.40
5	1.03	0.09	3.3	11.06	4.00
6	1.60	0.12	63	4.55	0.40
7	1.40	0.06	32	4.94	2.33
8	0.48	0.06	-5	9.83	2.47
9	0.32	0.10	9.3	8.52	3.20

Traditional workload thresholds for these measurements have been established in previous studies. Though GSR workload thresholds generally depend on the context, lower values are correlated to lower CW and vice versa (Arthur, 1990). Average GSR values tend to range from 0.3 to 1.3 uS, with high CW events raising the value as high as 8 uS in rare scenarios (Braithwaite et al., 2013). The GSR for the participants in this study generally fell within expected to higher than expected values for normal CW. For RMSSD, lower values tend to indicate higher CW, with values greater than .1 usually being indicators of lower CW (Tjolleng et al., 2017). Knowing the average age of participants and how that affects their average RMSSD, the CW indicated was average or higher than average in value for each participant compared to mean values for people of similar age (Abhishekh et al., 2013).

Regarding pupillometry data, it has been reported that the normal spontaneous blink rate is between 12 and 15 blinks/min. A mean blink rate of up to 22 blinks/min has been reported under relaxed conditions (Abusharha, 2017). Eye blinks and blink duration decrease as visual workload increases (De Waard & Brookhuis, 1996). Considering the visual demands of the driving and displays in the vehicle, it is reasonable to assume that officers were under high visual workload. Except for participant 2, the blink rate results supported De Waard and Brookhuis' study with low blink rates. Higher positive values of PCPS are correlated to higher workload (Pfleging et al., 2016). A previous study on police officers with an average of 7.92 years of experience demonstrated average PCPS values of 10.99% in driving simulator tasks (Zahabi et al., 2021). What this means for the results is that the majority of nLEO participants had a similar or higher average PCPS during the ride-along compared to the average value for more experienced officers. Those that did not have a significant change in PCPS may be explained by environmental conditions encountered during the course of naturalistic observation, such as frequent lighting changes.

AOI data

Though the surfaces measured varied slightly between participants due to variation in the technologies used by each participant in their vehicle, the following four surfaces were consistently measured: the dashboard, radio, MCT, and windshield for a baseline. The average proportion of time that a participant fixated on these surfaces during the pilot test was 0.7%, 1.8%, 1.1%, and 13.5% respectively. This indicated that participants primarily fixated on the road while driving and were unable to fixate on their in-vehicle technology for extended periods of time when not stopped. Other surfaces measured for specific participants such as speedometers and navigation aids produced similar results.

Subjective data

In addition to the physiological measures taken, DALI was administered to measure participants' workload subjectively after the experiment. Reported in Table 1 is the rating provided by the DALI for participants' subjective mental workload, with higher ratings indicating higher mental workload. Ratings could range from 0 to 5 based on participants' responses, but only 2 participants rated their mental workload above 2.5. This indicated that most participants were unable to accurately rank their own CW when comparing their responses to the physiological data.

DISCUSSION

The approach taken to synchronize the data for this pilot study was unique among other naturalistic observation studies. In order to ensure that multiple physiological measures could not only be collected but synchronized between stop times it was necessary to develop a novel way of tracking events between recording start and stop times. For many driver observation studies and particularly ones where the participant must frequently enter and exit the vehicle it is difficult if not impossible to maintain a wireless link between all devices being used to collect data in order to synchronize start and stop times. The procedure used in this study has the potential to solve this problem for similar naturalistic observation studies to this one. This procedure can be carried out with any equipment that allows users to take timestamps of their data as long as they have the same set time as each other, preferably UNIX time. In other naturalistic driving studies that require participants to exit their vehicles, this can be an invaluable tool. What all of these physiological measures indicate is that nLEOs tend to have average or higher CW values while completing their tasks as opposed to normal values and even more experienced police officers in simulated situations. In particular, blink rate was substantially lower and RMSSD were higher for nLEOs, on average when compared to standard values indicating normal CW. Given the lack of studies investigating CW of LEOs with these measures, more studies are necessary to completely validate these findings.

The subjective assessment suggests that nLEOs are not effective at evaluating their own CW, as the ratings are not consistent with the CW thresholds indicated by the physiological results. It has been well studied that subjective measures are limited due to recall bias and substantial individual differences (Hart, 2006). This is important to keep in mind for the development of new technology, which will have to contend with the fact that nLEOs may not have a clear grasp of the challenges they face when on patrol. In addition,it implies that there is a need for using DALI carefully with nLEOs as it cannot always appropriately reflect their CW.

Given the higher risk of motor vehicle crashes for LEOs, technology that focuses on reducing CW for the subset of novice officers with higher CW is critical. Observations during this pilot study noticed that officers frequently encountered input errors when typing on their MCT or had to pause what they were doing to ask dispatch questions when messages were not delivered clearly. These events drew attentional resources away from the driving task in line with multiple resource theory and increased the risk of crashes more than it would have for expert police officers that would be presumed to make fewer mistakes (Wickens, 2008). In-vehicle technologies such as the MCT and the dispatch radio need to be redesigned to be more user-friendly and accommodate the high CW experienced by novice officers in order to reduce crash related fatalities.

To meet this challenge, future work in human factors should strive to understand what specific challenges officers face in using the technology. Some of these challenges are brought about by the high CW demonstrated by the nLEOs in this study, and future studies should investigate the differences in CW in specific situations between LEOs and nLEOs to better determine what technologies used on the job have the largest impact on CW overall. This knowledge should then be used to design more robust and less cognitively demanding in-vehicle technologies for LEOs.

Limitations and future work

Several limitations caused by the nature of naturalistic driving study made data collection and post-processing difficult. Weather conditions such as direct sunlight sometimes prevented the eye tracking glasses from detecting the markers placed on different AOIs. This effect was most impactful on participant 6's PCPS data, as the 5-minute intervals towards the end of the recording when the sun had nearly set and the shadows cast by direct sunlight present throughout the evening increased the average pupil diameter of the participant and increased the overall resulting PCPS. Later participants were recorded at earlier times to compensate for this issue. Because data could not be collected while the participant was not in the vehicle, effects of the job participants were doing outside the vehicle on physiological variables could not be accurately measured and had to be inferred from data collected when they returned to the vehicle.Secondary tasks within the vehicle that were unrelated to the job at hand (e.g. non-work phone calls, eating) also created intrusiveness on getting accurate readings of the participants as they worked. Participants 4 and 8 in particular took more breaks than the other participants, which may have contributed to their PCPS reading being much closer to 0 than the other participants.

Prior studies using PCPS as a measure captured the baseline data before and after the completion of the study (Zahabi et al., 2021). However, in this study, we observed that the baselines collected before the data collection tended to be vastly larger than the baseline values collected at the end of the data collection. This led to several baseline recordings taken at the beginning of data collection being removed. Potential reasons for this issue include the time of day being morning and anticipation of the experiment introducing stress that increases the pupil diameter beyond baseline size. Because of these issues, the initial baseline collection was not as informative as the baseline collected at the end of data collection for the majority of participants.

Future studies can mitigate these limitations by being more selective with the time of day and weather for data sampling. Collecting data in the mornings or evenings as well as on cloudy days will reduce the chances of data loss for the eye tracking measurements. Though it might infringe somewhat on naturalistic observation, imposing calibration periods after officers stop and return to their car could help mitigate the effects of their work outside the vehicle on CW. Other studies that intend to collect physiological data on drivers can also make use of the synchronization method outlined in this pilot study for their own data collection equipment as long as a device able to take timestamps such as the E4 is used.

CONCLUSION

The findings of this study revealed that nLEOs exhibited higher CW compared to normal ranges while self-reported measurements could not show sensitivity to explain nLEO's CW. Therefore, it can be concluded that nLEOs execute their missions under high CW. As a second contribution, the synchronization approach in this study can be applied to future naturalistic driving studies, as it considered not only experimental devices but also the activation and deactivation of other devices in a police vehicle. Another contribution of this study was the finding that using physiological measurements might be more appropriate for assessing nLEO's CW than subjective assessment, although a detailed experimental protocol for device calibration and post processing under dynamic weather condition is required. Future studies should validate the findings of this pilot study with larger sample size and more thorough evaluation of participants' CW using both subjective and physiological measures. Finally, the results of this study are based on descriptive statistics and need to be validated using inferential statistics using the data from a larger sample.

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