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Original Article

The Effects of Fatigue on Cognitive Performance in Police Officers and Staff During a Forward Rotating Shift Pattern

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ABSTRACT

Background: Few studies have examined the effects of a forward rotating shift pattern on police employee performance and well-being. This study sought to compare sleep duration, cognitive performance, and vigilance at the start and end of each shift within a three-shift, forward rotating shift pattern, common in United Kingdom police forces.

Methods: Twenty-three police employee participants were recruited from North Yorkshire Police (mean age, 43 years). The participants were all working the same, 10-day, forward rotating shift pattern. No other exclusion criteria were stipulated. Sleep data were gathered using both actigraphy and self-reported methods; cognitive performance and vigilance were assessed using a customized test battery, comprising five tests: motor praxis task, visual object learning task, NBACK, digital symbol substitution task, and psychomotor vigilance test. Statistical comparisons were conducted, taking into account the shift type, shift number, and the start and end of each shift worked.

Results: Sleep duration was found to be significantly reduced after night shifts. Results showed a significant main effect of shift type in the visual object learning task and NBACK task and also a significant main effect of start/end in the digital symbol substitution task, along with a number of significant interactions.

Conclusion: The results of the tests indicated that learning and practice effects may have an effect on results of some of the tests. However, it is also possible that due to the fast rotating nature of the shift pattern, participants did not adjust to any particular shift; hence, their performance in the cognitive and vigilance tests did not suffer significantly as a result of this particular shift pattern.

1. Introduction

Rest and sleep are fundamental to the ability to drive safely and also to physical and mental wellb-eing; when these are reduced, so too is the ability to function normally and carry out tasks efficiently and safely [1]. The guideline for undisturbed sleep duration in healthy adults is between 7 and 9 hours [2] in a 24-hour period. This daily rest period is overseen by the circadian rhythm [3], and loss of sleep has been shown to result in changes in mood, cognitive impairment, and abnormal hormone rhythms [4]. The internal body clock or circadian process that regulates the daily rhythms of the body and brain [4] runs over a 24-hour period, strongly influenced by the natural cycles of light and dark. At night, many of the processes that are active in humans during the day start to slow down as our bodies prepare for sleep. The circadian process also stimulates night-time release of the “sleep hormone” melatonin, which lowers alertness and increases the need for sleep [5]. There are two main sleepiness peaks for humans over the 24-hour period, generally around 0300-0500 hours and 1400-1600 hours. Working at night is therefore likely to disrupt these rhythms, disturbing alertness when the body is ready for sleep [5]. Research shows that it is at these times that we experience our worst physical and mental performance of the day [6]. It is also between these times that there is an increase in fatigue-related road traffic collisions [7,8].

Many individuals, such as police and other emergency service personnel, work at night and are thus required to function when alertness, vigilance, and cognitive reasoning are at their lowest [5]. Shift work and fatigue have been shown to interfere with sleep and impair cognitive function [9,10]; therefore, a fatigued person is less

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alert, is less able to process information, and has slower reaction times [11]. After around 24 hours of sleep deprivation, alertness shows a marked decline, and performance impairment is in line with that of a blood alcohol concentration of 100 mg of alcohol per 100 mL of blood [12,13]. This is above the current drink drive limit, set in England and Wales, of 80 mg of alcohol in 100 mL of blood. Disturbed sleep is perhaps the major outcome of shift work [14], and working night shifts is shown to reduce average sleep by around 2 hours in any 24-hour period compared to the average sleep recorded for those working during the day [15].

In the United Kingdom, more than 3.5 million people are employed as shift workers, operating in a wide variety of industries [16]. Shift work is a pattern of work outside the standard working day and week, usually associated with office practices, in which one employee replaces another in the same role within a 24-hour period [17,18]. Shifts, which are becoming more prevalent in Western societies [19], can either be fixed, allowing employees to work the same shift on a regular basis, or they can be rotating. In some rotating shift systems, each team will regularly change its hours of work and rotate morning, afternoon, and night shifts. Continual shift systems provide cover for 24 hours, 7 days a week, and intermittent shift systems provide cover for less than the total hours available in a week, for example, five 24-hour periods in 7 days or 12 hours out of 24 [20]. Shift work is essential to societies because many operations are either not economically viable or simply impossible to run without relying on round-the-clock operations [21].

Different combinations of schedules have been used for rotating shifts, and research suggests that rotating-shift workers are prone to more problems than fixed-shift workers [22], which is considered to be due to sleep deprivation and misalignment of circadian phases. For example, self-reporting questionnaire studies of hospital-based nurses showed that when compared with day shift nurses, those working rotating shifts had more sleep disruption and were more prone to "nodding off" at work. This group of nurses were also more likely to nod off while driving home or be involved in reportable vehicle collisions and errors associated with sleepiness [22,23]. On the other hand, Harma et al [24] compared a more traditional backward rotating shift system, with a fast forward rotating system and found that the fast rotating, forward shift pattern actually had positive effects and improved well-being and alertness and reduced complaints related to lack of sleep.

Police officers and staff employed in the 43 police forces in England and Wales usually have to work shifts and irregular hours. Currently, each force sets its own shift patterns in accordance with factors such as demand for service, officer numbers, and local geography. In rotating shift patterns adopted by police forces, each team regularly changes its hours of work and rotates day, afternoon, and night shifts, providing continuous cover for 24 hours a day, 7 days a week. This continuous cover is essential as police work involves a number of both proactive and reactive responses, depending on numerous factors such as crime trends and demands for service from the public. When not dealing with specific incidents, police officers are usually driving, at all times of day and night, patrolling crime "hot spots" or other target areas.

Driving while tired is not unusual, with research showing fatigue to be a major contributory factor in road traffic collisions worldwide [25] and that a significant proportion of those collisions tend to involve serious injuries or fatalities [26]. Based on a review of international literature, Jackson et al [27] stated that driver fatigue could be a contributory factor in 20% of road traffic collisions, whereas figures published by the Department for Transport [28] suggest that fatigue was a contributory factor in just 2% of all road-related collisions in the United Kingdom. However, the Department for Transport collision data, collated as part of an investigation by police officers, are reliant on the evidence available at the scene. Unfortunately, there is currently no effective method for measuring driver fatigue during a journey [25], and when police officers interview drivers after collision, they often appear to be alert, possibly due to the collision itself. In these circumstances, fatigue is often not recognized or identified as the immediate precursor to the collision, with other causation factors recorded by the attending officer, for example, that the "driver failed to look properly". In addition, police officers do not attend every road traffic collision in the United Kingdom, as may be the case in other countries.

Sleep deprivation or fragmentation, such as that found in shift workers, is shown to affect cognitive performance [29,30] and is also thought to be associated with increased driver impairment and risk of collision [31]. Driving is a complex divided attention task using a number of physical and mental processes, and any assessments to illustrate differences in driving performance due to fatigue need to be reliable indicators of those wakeful functions that are affected by lack of sleep [31]. There are a variety of tasks that can be examined in a safe and controlled environment to replicate key processes involved with the cognitive components of driving. These are designed to simulate performance during driving during which the driver needs to remain vigilant and be in a position to change or take on an additional task, as and when required [32]. Specific functions including working memory, visual attention, psychomotor speed, shape perception, and praxis processes for conducting movements relating to control of the vehicle are noticeably susceptible to sleep loss, with some individuals more susceptible than others [33,34]. These cognitive domains are associated with risk of collision while driving; therefore, lower scores in simulated tasks are associated with higher collision risk [35]. A variety of cognitive tasks have been used to demonstrate the impact that lack of sleep has on cognitive performance [6] and aspects of driving [36] and to study the effects of fatigue. As such, there has been an increase in demand for batteries of tests to use in this context as research in this field grows [37]. A driver needs to be in a position to analyze what they see and process information quickly and accurately to react appropriately to unfolding events; test batteries provide a safe alternative to on-road testing of fitness to drive in a variety of situations [38].

The current authors [39] conducted a study on 523 police officers and staff working a variety of shift patterns in the Yorkshire and Humber region in the UK, which identified feelings of fatigue to be particularly prevalent for commutes to and from work in this group. From the 492 fully completed questionnaires, 94% of respondents indicated that they commuted by car, 6% of respondents stated that they had been involved in a collision or road departure while traveling to or from work, and 52% stated that they had been involved in a "near-miss" incident such as a curb strike or lane departure. Results also showed that 96% of these incidents occurred while traveling home from work and 62% of those had been working a night shift before reporting the incident. All respondents considered these incidents to be linked to driver fatigue. However, these were self-reported data, so a more objective means of exploring the problem was needed.

The present study was conducted on serving police officers and staff from North Yorkshire Police, who worked a 10-day forward rotating shift pattern. The aim of the study was to investigate the differences in sleep duration across the different shifts, along with performance on cognitive and vigilance tasks at the beginning and end of each shift within that pattern, to identify if fatigue was present which may adversely affect the participants during their commute. Taylor et al [39] found that traveling home from work, particularly after night shifts, was a problem with this sample of drivers. Therefore, it was hypothesized that performance on cognitive and vigilance tasks would also vary for this sample of police staff, being at its worst at the end of the shift, particularly the night shift, due to reduced sleep length, circadian rhythm effects, and/or poorer sleep quality associated with night shifts.

2. Materials and methods

2.1. Participants

Twenty-three police officers and staff (n = 18 officers, 5 staff) aged 31–54 years (mean age 43, 21 males, 2 females) from North Yorkshire Police participated in this study. They were all recruited by means of an Internet-based appeal for expressions of interest. Some of the participants (10) had previously participated in the study conducted by Taylor et al [39] and had expressed an interest in participating in further studies. All participants had a full UK driving license and drove to and from work. The police staff members worked in the control room, and although they drove to and from their place of work, they were not required to drive as part of their duties, whereas the police officers were required to drive during duty times. Five of the police officers held a standard police driving qualification, and 13 held an advanced police driver qualification. Twenty-six percentage of participants had a commute of more than 30 minutes duration, each way.

All participants followed a three-shift, forward rotating shift pattern as shown in Table 1. Shift length and start time varied by weekday due to predicted demand for service from the public. The shift pattern consisted of two day shifts, beginning at 0700 hours; two afternoon shifts, beginning at either 1400, 1500, or 1700 hours (depending on day of the week); and two night shifts, beginning at 2200 hours, followed by four days' off. This was a constantly repeating 10-day pattern for participants, in which, after the four days' off, all officers and staff returned to the same working pattern. Ordinarily, following this pattern, all shifts varied in length from 8 to 10 hours. An additional training day, beginning at 0830 hours and of 9 hours' duration, is also incorporated in the pattern, once every 10 weeks. All participants provided their informed consent to take part in the study.

2.2. Measures

To understand the relationship between shift pattern and its effect on fatigue, objective and subjective levels of sleep were measured using actigraphy and sleep diaries. In addition, participants were required to complete a series of computer-based tests measuring vigilance and cognition at designated times during their shift. Each participant was involved in the study for one complete 10-day cycle of shifts.

2.2.1. Sleep duration

To record their activity and sleep/wake patterns, participants wore an actigraphy-type, iHealth [40] watch device, as shown in

Table 1
Ten-week forward rotating shift pattern.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1	Day	Day	Afternoon	Afternoon	Night	Night	Rest Day
Week 2	Rest day	Rest day	Rest day	Day	Day	Afternoon	Afternoon
Week 3	Night	Night	Rest day	Rest day	Rest day	Rest day	Day
Week 4	Day	Afternoon	Afternoon	Night	Night	Rest day	Rest day
Week 5	Rest day	Rest day	Day	Day	Afternoon	Afternoon	Night
Week 6	Night	Rest day	Rest day	Rest day	Rest day	Day	Day
Week 7	Afternoon	Afternoon	Night	Night	Rest day	Rest day	Rest day
Week 8	Rest day	Day	Day	Afternoon	Afternoon	Night	Night
Week 9	Rest day	Rest day	Rest day	Training	Day	Day	Afternoon
Week 10	Afternoon	Night	Night	Rest day	Rest day	Rest day	Rest day

Fig. 1. iHealth watch [40].

Fig. 1, on their nondominant wrist for the 10-day period. They were required to wear the watch for the duration of the study, with the exception of bath or shower times.

The iHealth watch can be easily switched between active and sleep mode by the touch of a button to distinguish between time awake and when a participant has a prolonged period of inactivity. It is capable of measuring time asleep, sleep efficiency, daily activity, and calories burnt. This study was only concerned with time asleep. The data are downloaded to the iHealth "app" for storage, examination, and presentation, allowing data to be compared on a day-to-day basis.

2.2.2. Sleep diary and incident report

Participants were required to complete a sleep diary and also provide other information such as alcohol and caffeine consumption or medication taken. They were also asked to note any driving incidents that occurred during the 10-day period. The sleep diary was adapted from the American Academy of Sleep Medicine diary [41] to suit the 10-day shift cycle. Participants were asked to keep the diary with them at all times, during both work and rest days, providing a subjective account of sleep duration, activity, stimulant, medication, and alcohol consumption and any driving incidents.

2.2.3. Cognitive and vigilance tests

To compare performance on the cognitive and vigilance tasks during the different shifts, participants completed a selection of tests, as close to the beginning and end of each working shift as possible. This was done for each of their six working shifts, during one complete 10-day shift and rest rotation. They were also required to complete the tests at the beginning of the first day shift on their return from rest days. Therefore, each participant completed the test battery on thirteen separate occasions, as shown in Fig. 2. However, they did not complete these tests on rest days as this study was only concerned with their performance at the beginning and end of each shift worked. Conducting the tests at the beginning and end of the different shifts also ensured that they were conducted at a time as close as possible to the participant's commute.

The tests were presented to participants on an iPad, using a neurobehavioral assessment tool called Joggle Research [42]. This programme provided the researcher with instant access to results through a secure Web-based interface. A battery of five tests, all of which have previously been used to conduct research on fatigue, vigilance, or cognitive impairment, as discussed in the following, was selected to examine reaction time as a proxy for adeptness in these tasks. The five tests used were as follows;

1) The motor praxis task (MPT) tests psychomotor speed and visual tracking. It requires participants to quickly touch a series of blue boxes as they appear on the screen. The boxes move around the screen and reduce in size on each occasion. A similar motor processing speed task was used by Gur et al [37] in their mouse practice task as part of a test battery to explore individual differences in cognitive areas. The results obtained supported the use of the test battery in neurocognitive impairment research.
2) The visual object learning task (VOLT) tests working memory and visual object learning. It consists of a learning phase and a recall phase. The learning phase requires participants to memorize 10 different sets of three-dimensional shapes as they are displayed on the screen, one at a time. The display shapes are visible to the participant for 5 seconds, with a 0.4-second interval between each shape. When the recall phase begins, participants are shown 20 three-dimensional shapes, consisting of the 10 shapes they have seen previously and 10 alternative shapes. They are then required to recall if they have seen a particular shape before. Participants must select one of four answers during the recall phase indicating if they have seen the shape before. The options given were "definitely yes" and "probably yes" (seen before) and "probably no" and "definitely no" (not seen before). The task is participant paced, and they are required to respond as quickly as possible. The images do not advance until the participant has selected an answer. McKenna et al [43] used a similar shape perception task as part of a test battery in a study of participants with various neurological conditions to identify those who were unsafe to drive, concluding that these types of test can be used to inform decisions relating to driver safety.
3) NBACK tests attention and working memory. It involves the presentation of one abstract image at a time that participants

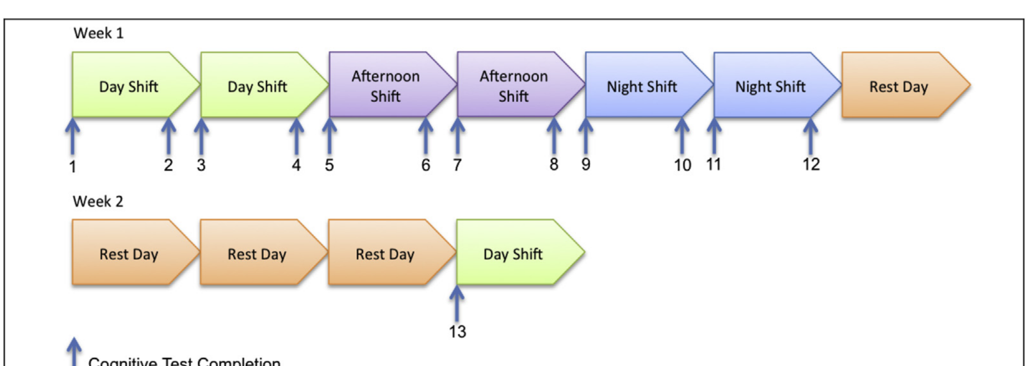

Fig. 2. Cognitive test completion schedule (completed 13 times).

are required to identify "n" trials ago (in this case, 2 images previous). The images proceed at a predefined timed sequence and continue to the completion of the task, irrespective of participant interaction. The image is displayed to the participant for 0.75 seconds with a 1-second gap between displays. A visual NBACK task was used by Smith et al [44] to examine the impact of sleep loss on working memory. Healthy adult participants were moderately sleep deprived in a laboratory setting and were found to respond more slowly and make more mistakes. A verbal NBACK task was used by Choo et al [45], who found that after 24 hours of sleep deprivation, performance and accuracy were negatively affected.

4) The digital symbol substitution task (DSST) tests attention, complex scanning, and visual tracking. It requires participants to identify and select a symbol identical to the target symbol shown on the screen. The task has a predetermined false start threshold of 0.1 seconds, so any reaction time less than this value will not be counted as a valid response. It also has a timeout threshold of 5 seconds, whereby if a response has not been received, the next stimulus is presented. DSST was used in a test battery by Chang et al [10] to examine impairment in different night shift patterns. Jackson et al [31] conducted similar studies using DSST as part of a test battery to examine sleep loss and cognitive performance. No significant findings were found in this case.
5) The psychomotor vigilance test (PVT) measures psychomotor speed and vigilant attention and is among the most widely used task for alertness [46]. It is reportedly most sensitive to sleep deprivation effects, is simple to perform, and is least prone to learning effects [47]. It requires participants to respond as quickly as possible to a visual stimulus appearing on the screen. A target box is displayed on the screen, inside which a millisecond timer appears. The participant touches anywhere on the screen as soon as possible after the stimulus begins. The reaction time is displayed after each response. This test lasted approximately 180 seconds. Although traditionally a 10-minute task, shorter PVT tasks have been shown to provide a reasonable substitute [48,49].

The stimuli for the MPT, DSST, and PVT were presented in a random order. The VOLT and NBACK task consisted of preconfigured sequences. The complete test battery took less than 10 minutes to complete.

2.3. Procedure

The study was conducted in the participants' own home and work environments. Each participant was first seen at his/her place of work at the beginning of the study, where he/she received a briefing and a printed information sheet providing sufficient information about the aims of the study and the procedures required. They were requested to keep to their usual routine for the duration of the study. All participants signed a consent form, agreeing to take part in the study. Participation in the study was completely voluntary, and participants were free to withdraw at any stage. The study was approved by the Ethical Committee of the University of Leeds, under ethics reference AREA 14-040. Participants were again visited, for debrief purposes, at the conclusion of the study.

2.4. Design

This study used a repeated measures design. For the statistical analysis of the sleep data recorded by means of the iHealth watches, there were two independent variables: shift type (with three levels: day shifts, afternoon shifts, and nights shifts) and shift number (with two levels: shift number 1, being the first shift of each day, afternoon, or night shift rotation, and shift number 2, being the second such shift). The dependent variable was the total time spent asleep after each shift.

A repeated measures design was used for the statistical analysis of the cognitive and vigilance tests, using the reaction time data collected during the test completion. There were three independent variables: shift type (with three levels: day shifts, afternoon shifts, and nights shifts), shift number (with two levels: shift number 1 and shift number 2), and start/end (with two levels: start of shift and end of shift). The dependent variable for each test was the average reaction time of the participants for each test.

3. Results

3.1. Sleep duration

Missing data from the iHealth watches were evident on occasions during which the participant had forgotten to switch from sleep to wake mode or vice versa or during which the battery had not been charged; however, this was minimal, amounting to 7% of overall data collected. One watch was damaged during the study, returning no data and rendering it unusable for any future studies; therefore, analysis was carried out with data from 22 participants. Multiple imputation was conducted using SPSS (IBM SPSS statistics V22) to generate alternatives for missing values, providing a complete data set [50,51]. The pooled output from multiple imputation estimated what the results would be in the original data set, had that data not been missing. The only constraint set within the process was the minimum value set at zero for the imputations generated. This effectively meant that the minimum possible sleep was zero minutes.

Results showed that there was a main effect of shift type on hours slept, $F(2,42) = 21.740$, $p < 0.001$, $\eta^2 = 0.509$, with mean sleep times being 7.79 hours after a day shift, 7.29 hours after an afternoon shift, and 5.62 hours after a night shift. There was no main effect of shift number, nor was there any interaction effect.

3.2. Sleep diary/incident report

Eight of the 23 participants took advantage of "napping" before their first, second, or both night shifts. Six of these naps were before the first night shift, and only one participant had a nap before both night shifts. Two male participants (one police officer and one staff member) reported driving incidents during the study. These incidents, one each for both participants, consisted of nodding off at the wheel while driving. One of these incidents was between 1500 and 1600 hours on a rest day; the other incident was between 0700 and 0800 hours, during a commute home from a night shift. That commute was in the region of one hour in duration. Both participants stopped their respective vehicles as soon as it was safe to do so and had a break, before continuing on their journey. The participant who reported the driving incident after a night shift had not had a nap before that night shift.

There was nothing of note with regard to reported alcohol intake, medication, or stimulant drinks consumed.

The mean self-reported sleep duration was 6.92 hours (standard deviation = 1.90), whereas that recorded by the iHealth watch was 7.09 hours (standard deviation = 2.13); a paired samples *t* test confirmed that there was no significant difference indicating that the objective and subjective methods of measuring sleep duration provided similar results. Furthermore, a Pearson product−moment correlation analysis showed a significant, positive relationship between self-reported sleep duration and the iHealth watch data ($r = 0.685$, $n = 166$, $p = 0.000$). Therefore, increases in self-reported sleep were accompanied by increases in sleep as reported by the objective measure.

3.3. *Cognitive and vigilance tests*

Missing data, amounting to 8% of the overall data collected, were evident in the cognitive and vigilance tests. This was due to operational reasons, whereby staff and officers were immediately deployed to or involved in incidents at the beginning or end of their shifts, leaving them unable to complete the tests at the relevant times. There may also have been occasions when a participant simply forgot to complete them.

No significant differences were identified regarding gender or between officers and staff; however, there were only two female participants (1 officer and 1 staff member) and five staff members who participated in the study.

3.3.1. *Motor praxis task*

There were no significant main effects of the shift type, shift number, or start/end on reaction time for this task. However, there was a significant interaction between the shift type and the start/end time, $F(2,44) = 7.630$, $p = 0.001$, $\eta^2 = 0.258$; this can be seen in Fig. 3. Bonferroni *post hoc* comparisons showed that the mean reaction times were slower at the start of shift number 1 than at the end, but this was conversely so for shift number 2, suggesting some interaction between learning the task at the start of Shift 1 and boredom at the end of Shift 2.

3.3.2. *Visual object learning task*

Results showed that there was a main effect of shift type in the VOLT task, $F(2,44) = 29.907$, $p < 0.001$, $\eta^2 = 0.576$, such that reaction time was progressively faster moving from day to afternoon to night shifts. These results are perhaps counterintuitive to what was expected, with participants faster after the night shifts. There were no significant interaction effects for this task.

3.3.3. *NBACK*

There was a main effect of shift type in the NBACK task, $F(2,44) = 10.973$, $p < 0.001$, $\eta^2 = 0.333$, with faster responses seen after the afternoon shifts than the day shifts. This then slowed again for night shifts and, however, was still faster on night shifts than it was on day shifts. Bonferroni *post hoc* comparisons showed that the significant differences were between the day shifts and afternoon shifts and also between the day shifts and night shifts.

There was a significant interaction between shift type and shift number, $F(2,44) = 5.379$, $p = 0.008$, $\eta^2 = 0.196$. Bonferroni *post hoc* comparisons showed that significant effects were evident between both the day and night shift interaction with shift number and the afternoon and night shift interaction with shift number. This interaction effect can be seen in Fig. 4. There was also a significant interaction between shift number and start/end, $F(1,22) = 9.812$, $p = 0.005$, $\eta^2 = 0.308$, such that reaction time tended to become quicker between the start and end of the first shift and slower between the start and end of the second shift. This can be seen in Fig. 5.

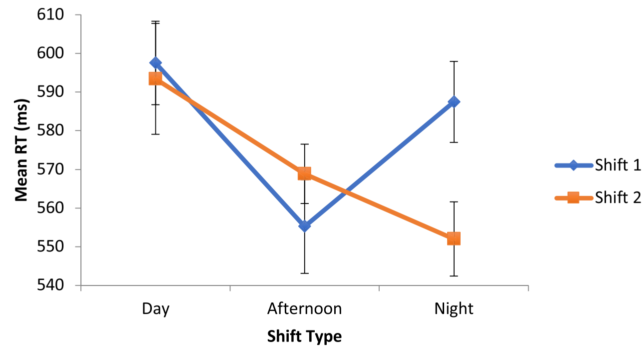

Fig. 4. Interaction effects of shift type and shift number for the NBACK task.

3.3.4. *Digital symbol substitution task*

There was a significant main effect of start/end, $F(1,22) = 4.430$, $p = 0.047$, $\eta^2 = 0.168$, such that reaction time was significantly faster at the start of the shift than at the end of the shift.

There was a significant interaction between shift type and start/end, $F(2,44) = 6.127$, $p = 0.004$, $\eta^2 = 0.218$. Bonferroni *post hoc* comparisons show that the significant differences were between the day shifts and night shifts. This interaction effect can be seen in Fig. 6. There was a significant interaction between shift type, shift number, and start/end, $F(2,44) = 4.930$, $p = 0.012$, $\eta^2 = 0.183$. *Post hoc* comparisons showed that the significant differences were between the day shifts and night shifts and also between the afternoon shifts and night shifts.

3.3.5. *Psychomotor vigilance test*

The results for the PVT indicated that there were no significant effects for any of the main effects or interactions. This task therefore failed to reject the null hypothesis.

3.4. *Learning effects*

Participants completed the test schedule on 13 separate occasions, as shown in Fig. 2. We hypothesized that the performance on Occasions 1 and 13 should be the same as at both these times,

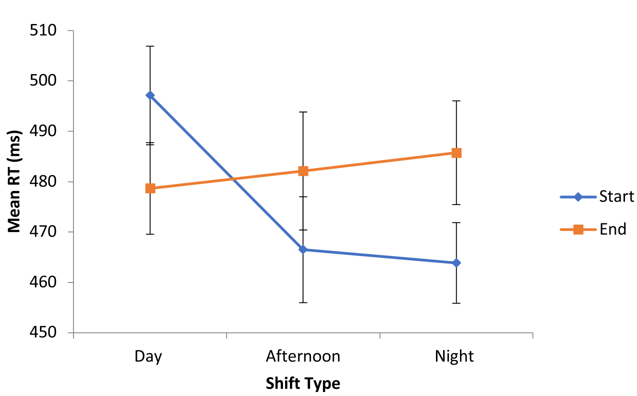

Fig. 3. Interaction effects of shift type and start/end of shift for the MPT task. MPT, motor praxis task; RT, reaction time.

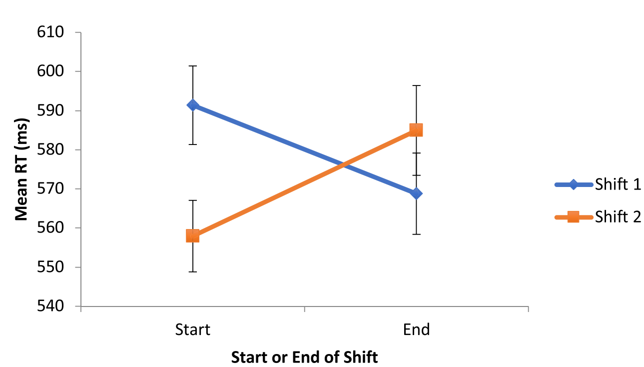

Fig. 5. Interaction effects of shift number and start/end of shift for the NBACK task.

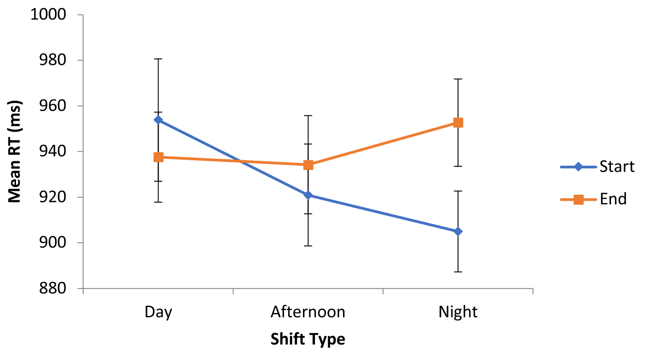

Fig. 6. Interaction effects of shift type and start/end of shift for the DSST task. DSST, digital symbol substitution task.

participants completed the tasks after a 4-day rest period. To consider the effects of learning, we compared these two and assumed that if learning effects were present, then reaction time on Occasion 13 would be quicker than that on Occasion 1. Results showed a significant difference for MPT: F(1,22) = 7.748, $p = 0.011$, $\eta^2 = 0.260$; VOLT: F(1,22) = 23.626, $p < 0.001$, $\eta^2 = 0.518$; and DSST: F(1,22) = 12.655, $p = 0.002$, $\eta^2 = 0.365$; with reaction time becoming faster, indicating that learning effects may have been present for these tasks. This was not observed for NBACK or PVT.

4. Discussion

This study sought to investigate how variations in sleep during a forward rotating shift pattern affect performance on a number of cognitive and vigilance tasks completed by 23 police service employees. Data collection was conducted in the participants' regular workplace and at home using a combination of sleep and incident diaries, actigraphy, and a cognitive test battery. Participants were serving police officers and staff who were working their normal duty shifts. The main aim of the study was to establish how sleep pattern and shift type affected participants' task and driving performance during their working hours and commute journeys.

The participants' self-reported data correlated with the objective watch data, regarding length of sleep, supporting the correspondence between both sources of measurement. Results showed that sleep duration was significantly reduced, by around 2 hours, while working night shifts. These findings are in agreement with those of a study by Torsvall et al [15], which also found that working a night shift reduced sleep duration in participants by around 2 hours. The implications of these findings are worth noting because they suggest that participants driving immediately after their night shift are likely to be more sleep deprived than recommended. The impact of this sleep deprivation and the risk to their own and others' safety on the road must be considered.

The selected cognitive and vigilance tests used in this study explored different aspects relevant to the driving task, such as sensory motor speed, visual attention, spatial working memory, complex scanning, visual tracking, and vigilant attention.

The test battery was completed by each participant on 13 separate occasions. With the exception of PVT, repeated use of cognitive tests can lead to learning and "practice effects" [52]. Results showed that despite the randomized nature of the cognitive tests and the varying test batteries used, learning effects may have been present for the MPT, VOLT, and DSST tests. This was not evident for NBACK and PVT.

The results for MPT, VOLT, NBACK, and DSST all supported the hypothesis, to a certain extent, that there was a difference in cognitive performance at different times during the forward rotating shift pattern. However, these were not entirely as expected, with results tending to indicate that reaction time was faster after night shifts, during which time these were predicted to illustrate the worst performance, due to shorter sleep periods after night shifts.

The PVT used in this study had duration of approximately 180 seconds. Although the standard PVT is of 10-minute duration, Roach et al [48] and Basner et al [49] identified that a shorter PVT provided comparable results than the standard test. The PVT is reported to be sensitive to sleep loss and is a widely used task in sleep-related studies [6], and Balkin et al [47] reported that PVT was subject to the least learning effects when compared with other cognitive tests; this is supported by the findings in this study. On the other hand, Basner and Dinges [53] suggest, however, that a short PVT may be too short to detect changes in performance in participants who may only be moderately impaired and whose performance may suffer from "time on task" in the standard 10-minute PVT. It is possible that the participants in this study were only moderately impaired, which could account for the lack of any findings in this particular test.

Alternatively, the findings are in agreement with those of Harma et al [24] who suggest that the fast forward rotating shift pattern does not adversely affect alertness among participants. In addition, participants may have partly adjusted to their shift work pattern and are able to perform cognitive tests to a satisfactory standard at any time during their shift schedule [54,55]. A study by Philip et al [56], which compared young (aged below 30 years) and older subjects (30 years and above), demonstrated that the older driver group had a greater tolerance to driving-related fatigue. The participants in the present study were all aged between 31 and 54 years (mean age 43); hence, the results could tend toward greater tolerance to shift work and fatigue in these circumstances, supporting the suggestion that they were only moderately fatigued.

Shift work involves many different factors, such as differences in "body clock", personal demands of home life, and work/life balance that may affect a person's predisposition to adjusting to shift work [6,57]. Tamagawa et al [55] also suggest that police officers, in general, are extremely tolerant when faced with psychological challenges. It is possible that interparticipant rivalry, producing a degree of competition and motivation [6], existed to obtain the "best scores", and indeed, this factor was discussed with the researcher during the debrief on a number of occasions. Finally, it is possible that at the end of the shifts, participants were sufficiently alert and ready for the reward of going home and that the demand placed on them temporarily while conducting the tests raised their overall vigilance and alertness to mask any signs of fatigue [58].

The study was limited by the time-consuming nature of the tasks and the repeated measures conducted with each participant over a 10-day period, thus leading to the small sample size.

The tests used were conducted as close as possible to the beginning and end of each shift to consider the commuting times and not at typical times of circadian lows. There is therefore scope for further studies involving additional tests at these times, considering tests that may more readily identify those who are moderately fatigued or using a larger sample size or individual workload during the period of the study and alternative shift patterns. A simulator or on-road study of the drive home after work would also be an interesting future possibility to study what happens with participants when they have left the workplace and during their commute as increased adverse driving events have been reported during this time [39,59].

In summary, the findings of this study may be relevant to those in other populations working rotating shift patterns. The limitations are discussed previously; however, the particular shift pattern followed by participants in this study is common in United Kingdom police forces. The results indicate that participants coped well with the shift pattern, without being overly fatigued. This is positive feedback for those police forces already following this pattern and can be considered by others as part of their regular reviews into current shift patterns adopted throughout England and Wales.

Conflicts of interest

The authors have no conflicts of interest to declare.

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