

Title page

Title: Exploring Sleepiness and Stress Among London Bus Drivers: An On-Road Observational Study

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16 **Highlights**

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- 18 - Bus driver sleepiness and stress were investigated on a live bus route.
- 19 - Drivers experienced greater levels of sleepiness during an early morning shift.
- 20 - And experienced greater task-related fatigue and stress during a daytime shift.
- 21 - The experience of sleepiness differed between drivers.

Abstract

Bus driver sleepiness is commonplace but often goes unreported within the industry. Whilst past research has begun to shed a light on the prevalence, potential causes, and consequences of bus driver sleepiness, this is often done using self-report methods. This is the first study to investigate sleepiness amongst city bus drivers on-road using a live bus route with drivers' regular schedules. A total of 16 participants completed two drives of their regular bus route once during an early morning shift and once during a daytime shift whilst physiological and self-report measures of sleep and stress were taken. Prior to these drives, drivers recorded their sleep in a diary and wore an actigraph to obtain objective sleep measures. Results showed that most drivers did not obtain sufficient sleep prior to early morning shifts, and often did not obtain as much sleep as they would need in order to feel rested before work. Sleepiness and stress were observed in both shifts. During early morning shifts sleepiness was likely a result of working during circadian lows and not obtaining enough sleep prior to the shift. In contrast, sleepiness during the daytime shift was likely a result of completing a highly demanding task in complex traffic which not only contributed to fatigue, but also led to increased levels of stress. As well as demonstrating the prevalence of sleepiness amongst bus drivers, these findings show that the causes of sleepiness can be multifaceted and often come about due to a combination of work and personal factors. In addition, the experience of sleepiness is not the same for all drivers, with individual differences in the experience of sleepiness playing a large role. These differences highlight the need for individualised interventions which should be considered by policymakers alongside the combination of causal factors within a larger systems approach.

Keywords: Bus driver; sleepiness; fatigue; driver sleepiness; on-road observation

1. Introduction

Driver sleepiness and fatigue are widespread, with 41% of drivers reporting falling asleep at least once in their lifetime when driving and 27% of drivers reporting difficulties in keeping their eyes open whilst driving within the previous month (Tefft, 2010). In Europe, approximately 20% of drivers reported driving whilst sleepy at least once in the previous month (Goldenbeld & Nikolaou, 2019). Driver sleepiness is a significant risk factor for motor vehicle incidents (Bioulac et al., 2017) and is estimated to contribute to 15-20% of all road crashes globally (Hallvig et al., 2014; SWOV, 2019; Zwahlen et al., 2016).

Although sleepiness can be a problem for all drivers, it can be particularly prevalent amongst professional drivers engaging in shift work. Shift workers are susceptible to sleepiness as a result of multiple factors including long work hours, irregular shift patterns, working in a sedentary position, and general work-related demands (Gander et al., 2011; Öz et al., 2010). Another important factor is the timing of work, as working during points of the circadian low (e.g., during the night and early morning) can result in increased sleepiness and decreased alertness due to the combined influence of the circadian drive and sleep pressure (Åkerstedt & Folkard, 1997).

Bus drivers are one particular group of shift workers who are known to experience sleepiness and fatigue during work. It has been shown that sleepiness is a global problem for bus drivers. For instance, in a survey of Swedish bus drivers it was found that 45% had to fight sleepiness 2-4 times a month, whilst 19% had to fight sleepiness 2-3 times a week (Anund et al., 2016). Similarly a Scottish study showed that 12% of surveyed bus drivers had fallen asleep whilst driving the bus (Vennelle et al., 2010) and 74% of surveyed Peruvian drivers reported experiencing sleepiness whilst driving (Liendo et al., 2010).

In our own research on London bus drivers, it was found that sleepiness is commonplace. In a series of focus groups with 65 drivers, all participants reported experiencing sleepiness whilst driving the

bus however they did not feel comfortable reporting this to management (Maynard et al., 2021). This data also revealed that drivers often manage their sleepiness whilst driving using potentially ineffective countermeasures (Pilkington-Cheney et al., 2020). In a wide-ranging survey with over 1,300 participating bus drivers, it was found that 36% have to fight sleepiness whilst driving 2-4 times a month, with 21% having to fight sleepiness 2-3 times a week (similar to the results of the previous Swedish survey [Anund et al., 2016]) (Miller et al., 2020). Perhaps more concerning, this survey found that 221 respondents (17%) reported falling asleep at least once in the previous year whilst driving the bus, whilst 73 respondents (5%) reported having at least one sleep related crash in the previous year.

Together these findings suggest that sleepiness is highly prevalent amongst bus drivers and can lead to crashes on the road. The survey of London bus drivers (Miller et al., 2020) also identified several factors which contribute to drivers having to fight sleepiness, or having a sleep related close call whilst driving. Factors which were found to contribute to driver sleepiness included having a diagnosed sleep condition, poor self-reported sleep quality, high levels of stress, long working hours, having less than 11 hours between shifts, and variable start times. Overall, the results revealed that the strongest contributors to drivers having to fight sleepiness were their overall feelings of sleepiness and impaired waking as defined by the Karolinska Sleep Questionnaire (Åkerstedt et al., 2002), as well as enjoyment from driving (which was seen as a protective factor). Similarly, the survey found that when predicting involvement in a close call incident, sleepiness and impaired waking were the most important factors as well as under sleeping and having nowhere to sit during breaks whilst on shift.

Whilst this research provides a good illustration of the prevalence and causes of sleepiness amongst bus drivers, the majority of findings are based on retrospective self-report. Little research has explored this on-road by observing drivers during their working hours. There are several reasons for this, mainly due to challenges associated with collecting such data. Firstly, it would be necessary to

recruit a number of bus drivers working on the same bus route in order to control for employment and driving context factors. This would require involvement from a bus operator who would have to grant access to participants as well as buses. Secondly, relevant equipment would need to be installed on buses to monitor driver sleepiness whilst not impeding the participant's ability to drive the bus and interact with their passengers. Finally, as shown in our previous focus group work (Maynard et al., 2021) bus drivers may not be willing to be observed during their shifts due to fear of repercussions if they are found to be sleepy whilst working.

Despite these challenges, one study which has explored bus driver sleepiness in a more naturalistic setting was conducted in Sweden (Anund et al., 2018). This study explored the differences in sleepiness amongst city bus drivers when taking part in a single afternoon drive, and an afternoon drive as part of a split shift (in which they had already completed an early morning drive followed by a long break), with sleepiness being recorded through self-reported Karolinska Sleepiness Scale (KSS) scores, electroencephalogram (EEG), and blink durations as measured by electrooculogram (EOG) throughout the drives. Data collection took place on a real 23km route which was similar to a typical city bus route. Drivers were also required to make stops during the route to collect passengers, however as the bus was out of service dummies were used to simulate real passengers. Results showed higher levels of sleepiness during split shifts, with 27% of drivers reporting KSS scores of 8 or higher indicating high levels of sleepiness. Whilst this study provides evidence of bus driver sleepiness on real roads, the setting is still not completely representative of an actual work shift for a bus driver due to the fact that the route was not a genuine bus route with real passengers and the associated additional pressures faced by bus drivers in their normal working life.

More recently, a pilot study monitored heart rate during normal driving among bus drivers to predict aberrant driving behaviour using machine learning models (Tsai et al., 2023). Although on-road data collection was focused on heart rate variability, self-report data revealed that drivers in the aberrant driving group obtained less sleep before shifts, had poorer sleep quality, and reported higher levels

of sleepiness. However, this study did not record any measure of sleepiness throughout the drive. Also investigating bus drivers, Diez et al. (2020) explored circadian rhythm interruptions amongst long haul bus drivers. Results revealed that sleep quality can vary significantly for drivers depending on the sleep location (for example, sleeping on the bus compared to the driver's own bed) as well as showing that drivers exposed to high-risk working schedules (where sleepiness will be more likely) exhibited weaker circadian temperature rhythms and variations in alertness. However, unlike the current research this study focused on long haul drivers completing long routes in the evening, as opposed to city bus drivers who will face different work conditions and challenges related to their sleepiness.

Research has also been conducted recording sleepiness amongst other shift working transport operators such as tram drivers whilst on shift (Onninen et al., 2021). In this study, drivers recorded their self-reported sleepiness using the KSS during a real shift, and recorded the factors which they believed caused any sleepiness. Once again, this study demonstrated that sleepiness is prevalent during shifts working as a professional driver. Although this study used a more naturalistic setting than previous work by recording self-reported sleepiness during a live route, the recorded data was all self-report. Additionally, sleepiness data has been collected on-road from shift-working long-haul truck drivers, using the KSS, actigraphy, and sleep logs (Pylkkönen et al., 2015). The data was considered in relation to different shifts, reporting that sleepiness was present within this population although there were differences depending on shift type. For example, there were differences in sleep duration before shifts, the likelihood of severe sleepiness was greatest on the first night shift ($KSS \geq 7$), and consecutive night shifts were more likely to be preceded by insufficient prior sleep. It is worth noting that the demands of tram and truck drivers differ from those of bus drivers. Tram drivers will not have to interact with passengers and are less likely to deal with traffic on the route. Truck drivers operate alone and have less restrictions in terms of timing and location of breaks or stopping during the drive. However, the consequences in terms of safe operation will be the same.

146 These past studies have demonstrated that sleepiness is a problem for drivers of passenger
147 transportation with multiple stops (i.e. bus and tram drivers), however most of these studies have
148 either relied entirely on self-report measures, or have investigated sleepiness on road in more
149 controlled settings which are not fully representative of a bus drivers typical shift. To date, no
150 research has investigated bus driver sleepiness on a live bus route with associated normal working
151 conditions, using a combination of self-report and objective measures of sleepiness. This study
152 aimed to address this gap by exploring bus driver sleepiness under normal driving operations, by
153 comparing sleepiness during a perceived sleepy shift (an early morning shift) and a perceived alert
154 shift (a daytime shift). This was achieved on real roads applying a highly ecological investigation
155 technique with a small number of London bus drivers taking part in their regular working shifts. This
156 method allows the current study to aim to provide a more in-depth report of the experience of bus
157 driver sleepiness including the amount of sleep obtained before shifts, the experience of sleepiness
158 whilst driving the bus, and the effects of sleepiness on driving performance.

159 The study used a repeated measures design where data was collected at two time points on the
160 same operational commercial bus route; these time points were an early morning drive (starting
161 before 7am) and a daytime drive (starting after 9am and before 3pm). These shifts were undertaken
162 as part of the participants normal working schedule, with participants being asked to not make any
163 changes to their driving or work practices during these observations.

164 With the agreement of the bus operator, the research team selected a bus route of sufficient length
165 to allow enough data to be recorded, sufficiently busy in terms of passenger numbers and traffic,
166 with enough drivers working on the route to take part. The route was fixed and the same journey
167 was therefore driven by all of the participating drivers. During each drive their self-reported
168 sleepiness, self-reported stress, blink duration, and heart rate were recorded together with the
169 amount of sleep obtained before each shift. To record blink duration and heart rate, as well as video

and audio recordings, equipment was installed on the buses for data collection; there was sufficient equipment to instrument two buses.

Sixteen drivers took part in the study on a voluntary basis. Electrodes were attached to the driver at one of the two starting points for the route with data collection occurring for one journey per shift from point A to point B (in either direction).

Several hypotheses are made. Firstly, we hypothesise that drivers will obtain less sleep prior to an early morning shift compared to a daytime shift. Secondly, we hypothesise that drivers will experience higher levels of sleepiness during the early morning shift compared to the daytime shift as measured by blink duration and self-reported sleepiness. Finally, we hypothesise that drivers will experience higher levels of stress during the daytime shift compared to the early morning shift as measured by heart rate variability and self-reported stress.

2. Method

2.1. Design

The study used a repeated measures design where data was collected at two time points on the same operational commercial bus route; these time points were an early morning drive (starting before 7am) and a daytime drive (starting after 9am and before 3pm). As these were real shifts, the exact start times for each participant differed. These times were informed by our previous research (Maynard et al., 2021; Miller et al., 2020) which suggested London bus drivers believed early morning shifts were more fatiguing than daytime shifts. The order in which participants completed each condition was dependent on their existing shift schedule for the duration of the study, with 11 drivers completing the early morning drive first, and 5 completing the daytime drive first.

The dependent variables in the study were: total sleep time (TST) and sleep onset latency (SOL) (as recorded by actigraphy) as well as self-reported sleep duration and sleep quality before each drive,

blink duration (ms) and heart rate variability (reported as the root mean square of successive differences between normal heartbeats [RMSSD]), during each drive, and self-reported sleepiness and stress during each drive through the Karolinska Sleepiness Scale (KSS) and the Stockholm University Stress Scale (SUS) (described in section 2.4).

2.2. Study setting

During the early stages of the study, an email was sent to all bus operating companies within London inviting expressions of interest to take part in the study. Three of the 10 operating companies responded with an expression of interest, and meetings were arranged to discuss the feasibility of running the study. During the meetings with these operators the details of the study, and whether the company had a suitable bus route, were discussed.

In order to be used for the study, the selected route needed to be of sufficient length to allow enough data to be recorded, sufficiently busy in terms of passenger numbers and traffic, have enough drivers working on the route to take part in the study, and use buses on which equipment could be installed.

Based on these discussions an operator and bus route were selected which met the above criteria. The selected route was staffed by 77 drivers excluding night shift drivers. Of those, 59 worked mixed shifts in which they drove during both early mornings and daytimes as part of their regular shift schedule. To avoid impacting drivers' existing shifts, the bus driver schedule for the entire route was used to invite drivers who were already scheduled to work an early morning and a daytime shift (based on the criteria described below) within the study period to take part in the research. Participation was voluntary for drivers working these shifts, however drivers not scheduled to work these shifts during the study period were not eligible to take part in the research.

To record blink duration and heart rate, as well as video and audio recordings, equipment was installed on the buses for data collection (described in section 2.4); there was only sufficient

217 equipment to instrument two buses. As a result, it was necessary to coordinate with the operator to
218 ensure that drivers taking part in the research were allocated the correct buses for their shift.
219 Drivers completing the early morning shift collected the bus from the depot at the start of the day,
220 so they were able to always collect the correct instrumented bus. However, when completing the
221 daytime shift, the driver collected the bus at a change point in the middle of the route where they
222 took over from an earlier driver who was not participating in the research. As such it was necessary
223 to work backwards from the participating driver to work out who would have the bus beforehand,
224 all the way back to the start of the day to ensure the correct instrumented bus left the depot in the
225 morning. Due to the complex logistical challenges involved in this, it was often necessary to arrange
226 for buses to be changed on the day of data collection to ensure the participating driver drove the
227 correct bus for their daytime drive. The two buses used in the study remained instrumented
228 throughout the study period, with the recording equipment switched on or off depending on
229 whether the driver was participating in the research.

230 As data was collected during a live commercial bus route in central London, a priority whilst
231 collecting data for this study was to ensure that buses ran to their planned schedule without delays
232 occurring as a result of the project. Therefore, it was of paramount importance that set up for data
233 collection was fast so as to avoid delays. To assist with this, electrodes were attached to the driver at
234 one of the two starting points for the route (described further below) with data collection occurring
235 for one journey per shift from point A to point B (in either direction). Due to the variety of different
236 shifts being worked by drivers participating in the study, the time taken to complete this
237 approximately 8-mile journey differed between the two shifts. Therefore, only data from the first to
238 the 49th minute of each drive was included in the analysis (which corresponded to the shortest time
239 taken to complete one complete journey in this study, although at peak times this journey could
240 take closer to 80 minutes). This allowed a direct comparison between the two different drives. For
241 analysis purposes several variables were averaged across 5-minute intervals from the start of the
242 drive to the 49th minute.

2.3. Participants

A total of 16 drivers took part in this study on a voluntary basis. All 16 participants were male, and their ages ranged from 35 to 57 years ($M = 46.13$, $SD = 6.37$). Whilst it is not possible to compare the mean age of drivers in this study to London bus drivers as a whole, the mean is similar to our previous survey of a larger sample of bus drivers with a mean age of 45 years (Miller et al., 2019). Participants reported having worked as a bus driver between 3 and 17 years ($M = 10.94$, $SD = 5.36$) and all were working at that time as a bus driver full time as their main source of employment. Participants' self-reported weekly hours worked ranged from 38 to 55 ($M = 44.31$, $SD = 5.53$). Participants were recruited among the drivers scheduled to work the selected bus route during the study period. In order to participate, drivers needed to have worked regularly as a bus driver for at least two years, not had more than three sick days within the previous two months, and to have agreed to take part in all aspects of the study including actigraphy, the sleep diary, and wearing electrodes during the test drive.

All participants gave informed consent and agreed to take part in the study; it received full ethical approval from Loughborough University Ethics Committee (HPSC reference number: C16-62)

2.4. Procedure and equipment

2.4.1. Before recorded drives

Before completing the recorded drives, participants were asked to complete a background questionnaire. This was a shortened version of the questionnaire used in our previous research into contributory factors to bus driver sleepiness (Miller et al., 2020) and included questions relating to demographics, sleep, work patterns, and general health. The questionnaire also included the Karolinska Sleep Questionnaire (KSQ) (Nordin et al., 2013) to assess sleep quality.

For the four nights prior to each of the recorded drives, participants logged their sleep using both a MotionWatch actigraph (MotionWatch, CamNTEch Ltd, Cambridge, UK) and by completing a sleep diary. The watch was worn around the driver's non-dominant wrist and recorded their movement throughout the day (Elbaz et al., 2012). The watch was worn day and night, except when bathing or showering. Participants were instructed to press an event marker button on the watch every time they went to bed and woke up. This was done for both sleep in the evening and for daytime naps.

In addition to the actigraphy watch, participants were asked to keep a sleep diary for the four days before each of the recorded drives. The diaries included questions about the previous night's sleep (sleep quantity, sleep quality and sleeping problems), and questions about sleepiness and experiences during the day.

2.4.2. Recorded drives

For the observed drives, participants drove the same route through Central London twice (during an early morning shift and a daytime shift). All testing took place in December 2018. In contrast to previous studies (Anund et al., 2018) the current data were collected during a live bus route as opposed to participants being observed on a private road, or on an out-of-service bus. Importantly, during data collection the drivers engaged with all elements of their normal shift including navigating traffic and passengers; participants were reminded to drive and behave as they would normally on their shift.

Blink duration and heart rate were recorded during the drives using a Vitaport 3 system. Electrodes for electrooculography (EOG) to record and detect blinks, and electrocardiography (ECG) to record electrical activity of the heart were placed on the face and on the body. The electrodes were placed mainly on the right side of the face, which was facing away from the passengers.

During each of the recorded drives, participants were also asked to report their subjective levels of sleepiness and stress every five minutes. The level of subjective sleepiness during each drive was

assessed by using the Karolinska Sleepiness Scale [KSS] (Åkerstedt & Gillberg, 1990). Individuals were required to indicate on a nine-point scale how sleepy they had felt (1 = extremely alert to 9 = very sleepy, can't stay awake) on average during the previous five minutes. This was reported verbally and recorded during the drive, with participants being signalled to report their sleepiness level by a beep from a mobile phone placed within the cab of the vehicle. KSS is a widely used measure of sleepiness which has been validated against objective measures of sleepiness (EEG) (Åkerstedt & Gillberg, 1990; Kaida et al., 2006), blink duration (Sandberg et al., 2011), and driving performance measures (Sagaspe et al., 2008; Sandberg et al., 2011).

Subjective stress level was assessed using the Stockholm University Stress Scale [SUS] (Dahlgren et al., 2005), which is a nine-point scale ranging from 1 (very low stress) to 9 (very high stress, at the limit of what I can stand) similar to the KSS. A modified version of this scale was recently validated for use in transport studies (Dahlman et al., 2024). This was also reported verbally and as an average for the previous 5 minutes. For both scales, participants were familiarised with how to report their sleepiness and stress before taking part in the study and were reminded of the scales before each recorded drive. A written copy of the scales was also present in the sleep diaries.

Every five minutes during the drive, the participants were prompted with a beeping sound to report sleepiness and stress into the microphone. They were instructed at the start of each drive to first give the rating for sleepiness and thereafter the rating for stress level. This method has been used in previous on-road investigations (Anund et al., 2018) and did not have a negative impact on driver safety. Drivers were also informed that if for any reason they were unable to report their sleepiness or stress (such as interacting with passengers or traffic controllers) then they should skip this reporting and continue after the next beep.

Buses were also equipped with a Vbox (Racelogic Ltd, Buckingham, UK), driver and road facing cameras, GPS, and a microphone which recorded throughout the drives.

During the study one of the team of researchers travelled on the bus with the driver in case of problems or queries from passengers. Data was recorded as participants drove from one terminus to the other. In cases where the bus was driven from the depot or a point in the middle of the route, data collection was not started until the participant had arrived at one of the terminuses.

2.4.3. After recorded drives

The testing session ended once a full trip between both terminuses had ended (one-way). At this point the electrodes were removed from the driver, and they were asked to complete an after-drive questionnaire. The questionnaire consisted of 10 questions and encompassed topics of sleepiness, stress, worry, if control was lost during the drive and if any countermeasure were used to stay awake.

2.5. Data pre-processing and analysis

For sleep data collected across the four nights prior to the recorded drives, actigraphy data was manually checked and compared against the sleep diaries, the actigraphy data was then analysed using MotionWare software to extract the total sleep time, sleep efficiency, and sleep onset latency. Statistical analyses were performed on sleep measures from the night before each drive as well as on mean total sleep time TST & SOL of the four days before each drive. Naps were included in the calculation of four-day averages.

To maintain consistency with KSS and SUS reporting, heart rate and blink duration were averaged across 5-minute blocks from the start of the drive until the 49th minute. This represented time on task and ensured that it was possible to make statistical comparisons between both drives (with 49 minutes representing the shorted duration taken to complete the route).

Heartbeats (peak R-waves) were extracted from the ECG signal, and the resulting R-R intervals were used to derive heart rate variability (HRV) (Laborde et al., 2017; Shaffer & Ginsberg, 2017). As stress

increases so will heart rate which will reduce the heart rate variability, whereas sleepiness and fatigue will reduce the heart rate and increase the heart rate variability. In this study, the HRV metric root mean square of successive R-R differences (RMSSD) will be reported.

The blink parameters were extracted from the vertical EOG signal with an automatic blink detection algorithm (Jammes et al., 2008). For analysis purposes, two blink duration-based parameters were calculated; the mean blink duration, and the percentage of eye blinks with a duration longer than 150 milliseconds (Fors et al., 2011).

Across the two drives, data was unbalanced in terms of the total time driven as the time taken to travel between the start and end point for a morning shift was often faster than the time taken to travel the same distance for the daytime shift due to increased traffic volume. To allow for comparisons between the two drives, data from minute 1 to minute 49 of each drive were included in the analysis, which corresponded to the time driven during the fastest morning drives. This allowed a direct comparison between the two different drives; in cases where a drive lasted longer, only the first 49 minutes of data were included in the analysis.

Data were analysed using a series of GLM ANOVAs in which the independent variables were the two drive conditions (Morning/ Daytime), the time on task (5-10-15-20-25-30-35- 40-45 minute) and the direction of travel (towards or away from the city centre). Participant was used as a random factor. The model included both main effects and 2-way interactions. A brief description of all variables reported in this paper can be found in the supplementary materials.

3. Results

3.1. Background questionnaire

Eleven of the 16 participants reported their overall general sleep quality as either quite good (n=8) or very good (n=3), three rated their sleep as neither good nor bad, whilst one participant rated their

359 sleep as quite bad (1 data point missing). Participants reported needing between five and 12 hours
360 sleep before a shift in order to feel rested ($M = 07h30m$, $SD = 01h39m$).

361 Eight of the participants reported never having to fight sleepiness whilst driving the bus, whilst five
362 reported occasionally having to fight sleepiness, and two drivers reported doing this 2-4 times a
363 month (1 data point missing). No participants reported having to stop the bus due to sleepiness,
364 falling asleep behind the wheel, or having a sleep related road crash within the previous 12 months.
365 However, two participants reported having at least one sleep related close call in the previous year,
366 with the same two participants also reporting wanting to stop the bus due to sleepiness at least
367 once in the previous year. It should be noted that the proportion of drivers reporting having to fight
368 sleepiness, having to stop the bus, or having a sleepiness related crash was lower than observed in
369 our previous work (Miller et al., 2020).

370 Most participants were either very satisfied ($n=6$) or quite satisfied ($n=5$) with their work schedule,
371 whilst two reported being neither satisfied nor unsatisfied, with a further two reporting being quite
372 unsatisfied (1 missing). When reporting enjoyment from bus driving on a scale ranging from 1 (no
373 enjoyment) to 10 (high enjoyment) scores ranged from 4-10 ($M = 8.07$, $SD = 2.09$) indicating a
374 general enjoyment for bus driving. When rating stress on a similar scale from 1 (no stress) to 10
375 (high stress), scores ranged between 1-8 ($M = 3.53$, $SD = 2.30$) illustrating variability between
376 participants in the amount of stress experienced.

377 Finally, commuting time ranged from 15 minutes to one hour 45 minutes ($M = 50$ minutes, $SD =$
378 24.28). Eleven participants reported their commute involving some form of public transport, five
379 reported driving as part of their commute, and six reported a form of active travel in their commute
380 (walking or cycling).

3.2. Sleep before shifts

Both self-reported sleep and total sleep time as measured by the actiwatch for the night before the recorded drives can be seen in Figure 1. On average drivers self-reported obtaining between 03h45m and 08h00m before their recorded early morning shift ($M = 07h30m$, $SD = 01h39m$); this was significantly shorter than self-reported sleep obtained before the daytime shift which ranged from 06h48m to 10h00m ($M = 08h04m$, $SD = 00h57m$) ($t(2) = 5.7$, $p = .03$, $d = 3.28$).

When compared to the amount of self-reported sleep needed to feel rested between shifts ($M = 07h30m$, $SD = 01h39m$) participants obtained significantly less sleep before their early morning shift ($t(7) = 3.02$, $p = .02$, $d = 1.01$), however there was no difference between sleep needed and self-reported sleep obtained before the daytime shift ($t(4) = 1.63$, $p = .18$, $d = .73$).

When looking at the TST before each of the recorded drives, there was also a significant difference in sleep obtained before the recorded early morning and daytime shift ($t(12) = 3.09$, $p = .01$, $d = .86$). TST before the early morning shift ranged from 02h08m to 06h31m ($M = 04h51m$, $SD = 01h21m$), whilst TST before the daytime shift ranged from 03h56m to 08h55m ($M = 06:11:54$, $SD = 01h28m$). Paired samples t-tests showed that the amount of sleep obtained before both of these shifts was significantly lower than the amount of sleep participants self-reported needing to feel rested (Morning: $t(13) = 4.21$, $p < .001$, $d = 1.13$; Daytime: $t(14) = 2.45$, $p < .001$, $d = .68$).

There was no difference in the amount of time taken to fall asleep (sleep onset latency) the night before a morning shift ($M = 18.46$ mins, $SD = 24.94$) compared to a daytime shift ($M = 9.77$ mins, $SD = 15.21$) ($t(12) = 1.00$, $p = .34$, $d = .28$).

A series of paired-samples t-tests revealed no difference in the amount of sleep obtained (self-reported and actiwatch) between the nights before the recorded drives, and other shifts at similar times during the study period (all p-values > 0.05).

Finally, the amount of sleep obtained before either shift was not correlated to the age of the drivers (all p-values > 0.05).

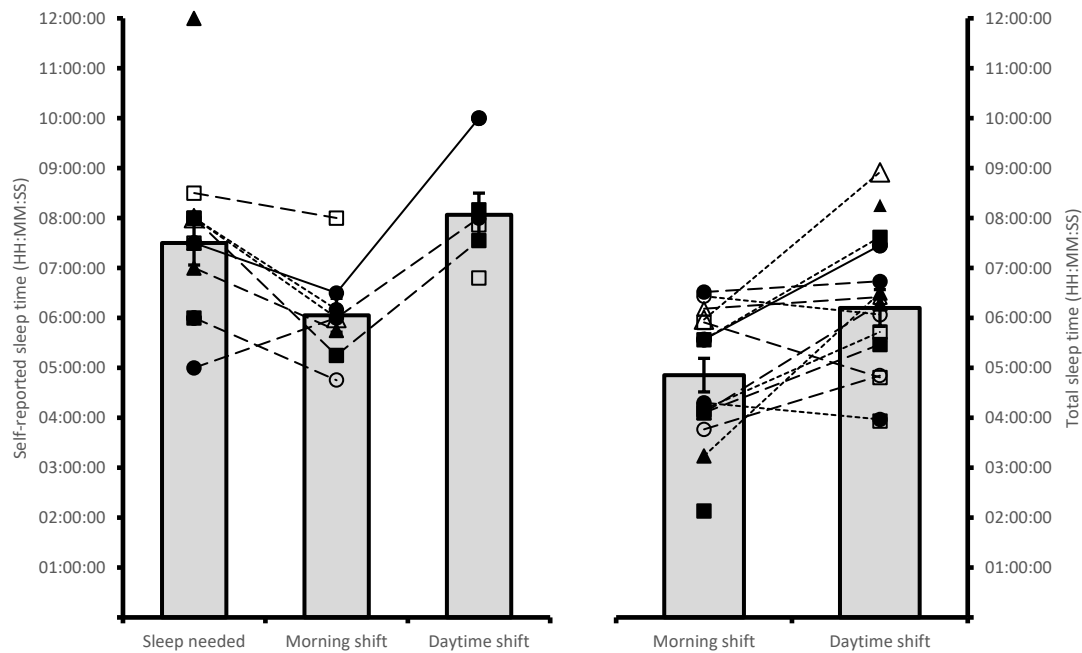


Figure 1: Left panel: Self-reported sleep needed, and sleep obtained before the morning shift and daytime shift. Right panel: Sleep obtained before the early morning and daytime shifts as measured by actigraphy. Each unique shape and their respective lines represent a single participant. In cases where only a single data point is present the participant did not have data for each shift. Error bars represent ± 1 SEM.

The self-reported reasons for not obtaining enough sleep (as recorded by the sleep-wake diary) can be seen in Figure 2. The most common reason was going to bed late, followed by starting work early the next morning.

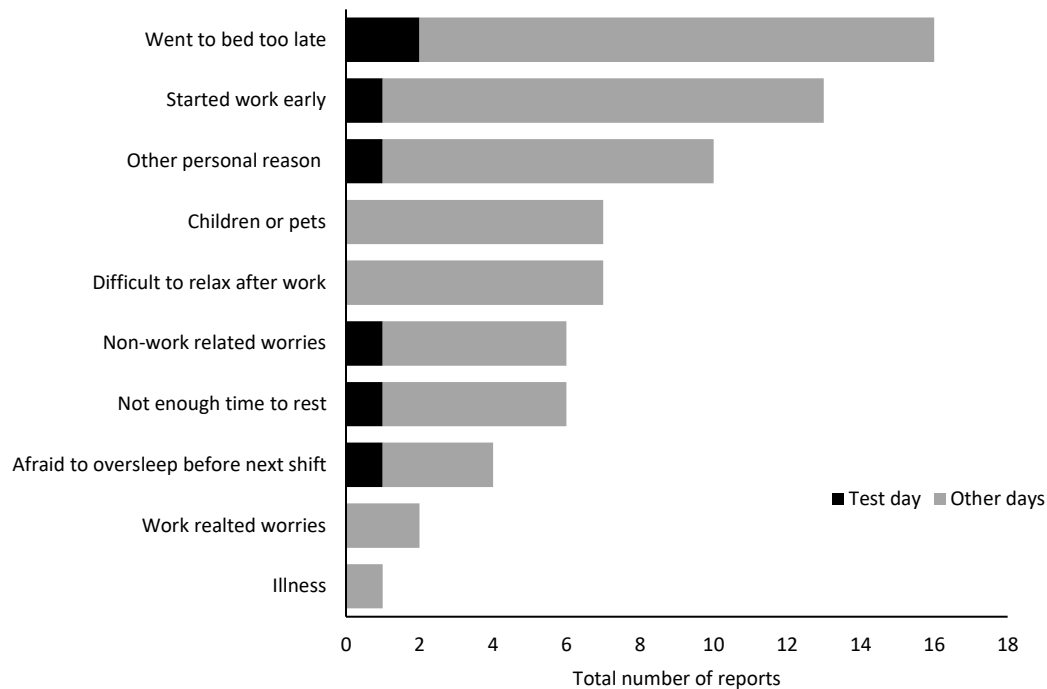


Figure 2: Self-reported reasons for not obtaining enough sleep. The black portion of the bar shows instances in which this was reported for the evening before one of the recorded drives, whilst the remainder of the bar shows the total number of reports across the study duration.

3.3. On-road variables

KSS, blink duration, SUS, and heart rate variability were each analysed using a GLM ANOVA with shift (early morning vs daytime), time on task (5-minute intervals from 5-45 minutes) and direction (towards or away from the city centre) as fixed factors, and participant as a random factor (see Table 1 for results). Figure 3 shows how each of these variables changed across the duration of the recorded drives, Figure 4 shows the mean for each participant on each trial.

Sleepiness measured with the KSS was significantly higher during the daytime drive ($M = 3.57$, $SD = 1.79$) compared to the early morning drive ($M = 3.24$, $SD = 1.21$). There was also a main effect of direction such that KSS was higher when travelling towards the city centre ($M = 3.83$, $SD = 1.67$) compared to travelling away ($M = 3.09$, $SD = 1.37$). However, there was no main effect of time on task. Finally, there was a significant 2-way interaction between shift condition and direction, such

430 that during the early morning drive KSS was higher when travelling away from the city centre,
431 however in the daytime shift KSS was higher when travelling towards the city centre.

432 The average blink duration was significantly longer during early morning drives ($M = 134\text{ms}$, $SD =$
433 27ms) compared to daytime drives ($M = 124\text{ms}$, $SD = 32\text{ms}$), however there were no effects of time
434 on task, direction, or any significant interactions.

435 There were no significant main effects or interactions when looking at the proportion of blink
436 durations $>150\text{ms}$. However, there were several instances in which the average blink duration across
437 a 5-minute interval was $>150\text{ms}$. Across the entire sample, the proportion of blinks $>150\text{ms}$ within a
438 5-minute interval ranged from 1.22% to 57.94% ($M = 16.77\%$, $SD = 10.68$), with 62% of participants
439 having at least one 5-minute interval in which their average blink duration was $>150\text{ms}$. Of particular
440 note is the case of one driver who showed an average blink duration $>150\text{ms}$ for every 5-minute
441 interval across both drives. The average blink duration within a 5-minute interval for this participant
442 ranged from 162ms to 295ms ($M = 203\text{ms}$, $SD = 0.031$). In each of the 5-minute recorded segments
443 of the drive, the proportion of individual blink durations above 150ms ranged from 29.12% to
444 69.57% ($M = 42.86\%$, $SD = 12.05$). Despite these long blink durations, this participant gave KSS
445 reports between 2 (very alert) and 5 (neither alert nor sleepy) ($M = 3.06$, $SD = 1.06$).

446 To explore the role of stress and physiological arousal during each drive, SUS and HRV (RMSSD) were
447 also subject to separate GLM ANOVAs. The average self-reported stress level measured with the SUS
448 was significantly higher during the early morning drive ($M = 3.02$, $SD = 0.68$) compared to the
449 daytime drive ($M = 2.95$, $SD = 1.50$). In total three SUS reports out of 163 (2%) were above 6, and
450 those were reported by two drivers and only during the daytime drive. There were no main effects
451 of time on task, or direction of travel and no interactions.

452 There was a significant difference between heart rate variability (HRV) during the early morning
453 drive ($M = 0.038$, $SD = 0.017$) compared to the daytime drive ($M = 0.032$, $SD = 0.130$) indicating

higher physiological toll and workload during daytime compared to the early morning drive. There was also a significant effect of direction with lower HRV (indicating higher workload) when travelling towards the city centre ($M = 0.032$, $SD = 0.005$) compared to travelling away from the city centre ($M = 0.037$, $SD = 0.004$). Finally, there was a significant interaction between shift and direction, during the morning drive HRV was lower when driving away from the city centre, whilst during the daytime shift HRV was lower when driving towards the city centre.

As with the amount of sleep obtained before shifts, none of the on-road variables were significantly correlated with the drivers age (all p -values > 0.05).

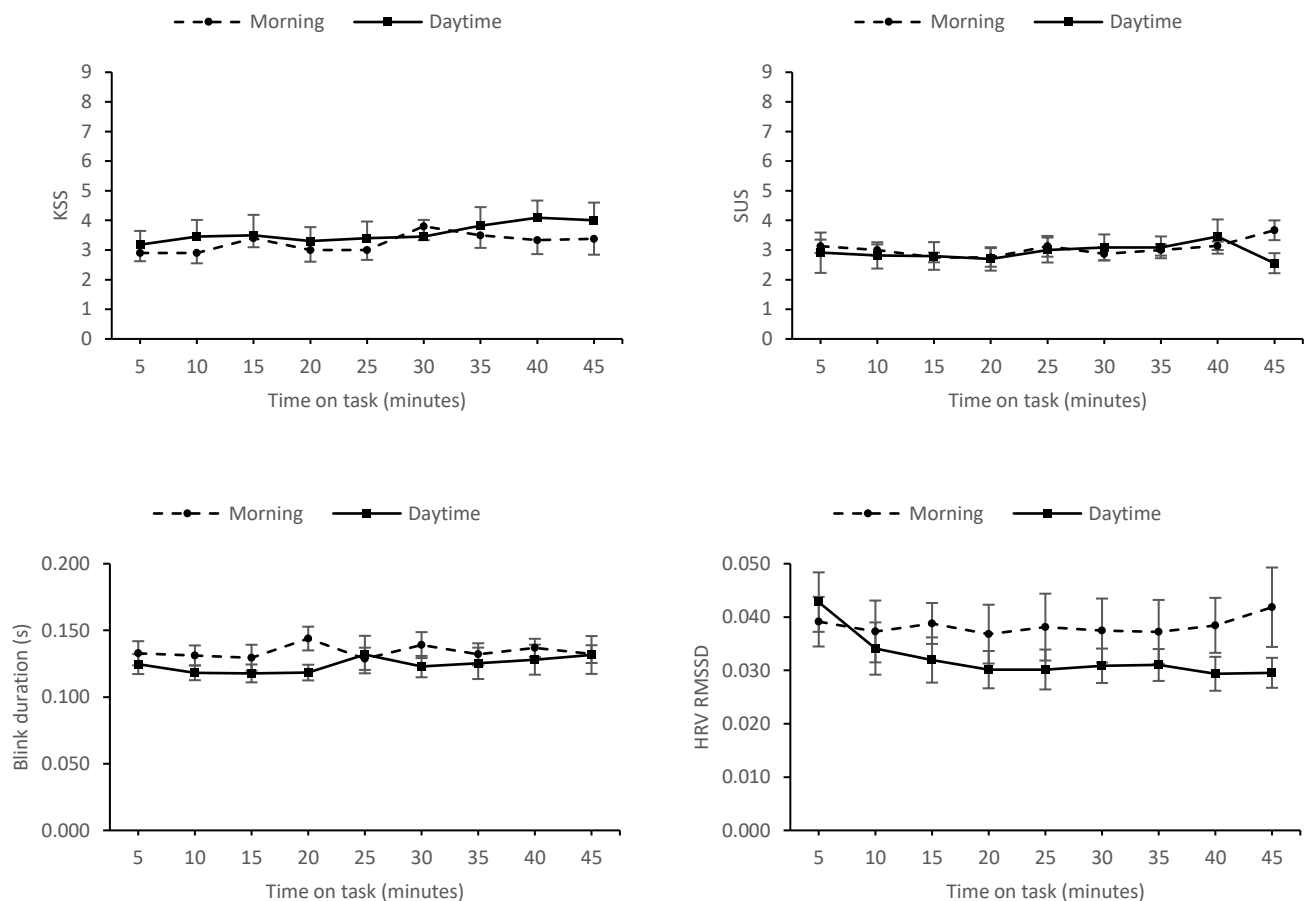


Figure 3: Sleepiness (KSS & blink duration) and stress (SUS and HRV) indicators across the 45-minute duration of each drive.

Error bars represent ± 1 SEM.

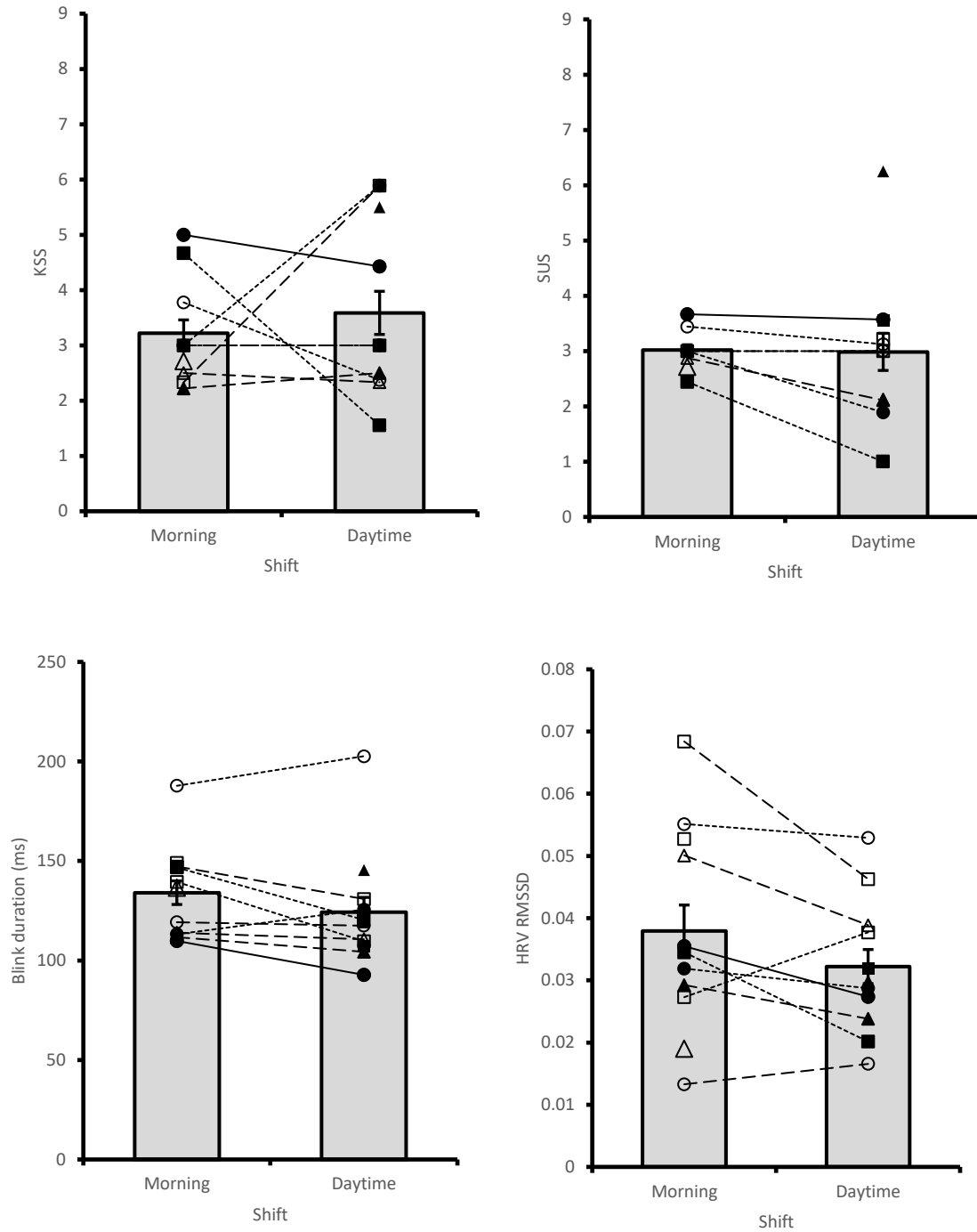


Figure 4: Mean KSS (top left), SUS (top right), blink duration (bottom left), and HRV (bottom right) for each participant across the early morning and daytime drives. Bars represent the overall mean in each condition. Error bars represent ± 1 SEM.

Table 1: ANOVA results for subjective and objective measures of sleepiness and stress during the recorded drives. Significant main effects and interactions are presented in bold.

	<i>F (df)</i>	<i>p</i>	<i>η²</i>
KSS			
Shift	10.093 (1, 142)	0.002	0.066
Time on task	0.950 (8, 142)	0.478	0.051
Direction	12.914 (1, 142)	<.001	0.083
Shift * Time	0.361 (8, 142)	0.939	0.020
Shift * Direction	8.335 (1, 142)	0.004	0.055
Time * Direction	0.418 (8, 142)	0.090	0.023
Blink duration			
Shift	7.082 (1, 156)	0.009	0.043
Time on task	0.735 (8, 156)	0.660	0.036
Direction	0.072 (1, 156)	0.788	<.001
Shift * Time	1.427 (8, 156)	0.189	0.068
Shift * Direction	0.049 (1, 156)	0.825	<.001
Time * Direction	0.435 (8, 156)	0.899	0.022
% of blink durations >150ms			
Shift	0.041 (1, 156)	0.840	<.001
Time on task	1.961 (8, 156)	0.055	0.091
Direction	0.752 (1, 156)	0.387	0.005
Shift * Time	0.617 (8, 156)	0.763	0.031
Shift * Direction	3.27 (1, 156)	0.072	0.021
Time * Direction	0.782 (8, 156)	0.620	0.039
SUS			
Shift	13.022 (1, 124)	<.001	0.095
Time on task	1.102 (8, 124)	0.366	0.066
Direction	0.174 (1, 124)	0.677	0.001
Shift * Time	0.691 (8, 124)	0.699	0.043
Shift * Direction	3.330 (1, 124)	0.070	0.026
Time * Direction	0.620 (8, 124)	0.760	0.038
HRV RMSSD			
Shift	44.790 (1, 156)	<.001	0.223
Time on task	1.732 (8, 156)	0.095	0.082
Direction	11.167 (1, 156)	0.001	0.067
Shift * Time	1.417 (8, 156)	0.193	0.068
Shift * Direction	21.758 (1, 156)	<.001	0.122
Time * Direction	1.336 (8, 156)	0.230	0.064

3.4. After drive questionnaire

When asked to rate how difficult it was to stay awake during the drive (with a score of 1 indicating not difficult at all and a score of 7 indicating very difficult), 80% of participants gave a score of either 1 or 2 indicating no difficulty in staying awake during the drive. There were two instances in which participants reported difficulties in staying awake during the drive (as indicated by a score of 6 with a maximum of 7) and both occurred during the daytime drive. When comparing scores between the two drives there was no significant difference ($z = 1.47$, $p = .14$).

Similarly, when asked to rate how stressful the drive was on a scale of 1-7, 83% of participants reported scores of 1 or 2 indicating low levels of stress when driving. There were two instances of scores indicating high stress (6 or 7) which both occurred during the daytime drive. When comparing scores between the morning and daytime drives there was no significant difference ($z = 1.63, p = .10$).

60% of participants indicated that the experimental drive was similar to a normal drive on the same route (as indicated by scores of 6 and 7 on a 7-point scale).

There were no instances where participants reporting losing control of the vehicle during the recorded drive, and only one instance in which a participant reported losing awareness for traffic during the daytime drive. Finally, there were eight instances in which a participant reported experiencing some level of sleepiness during the drive (five of which occurred during the early morning drive). However, due to the low number of instances, it was not possible to explore these differences statistically.

4. Discussion

This study aimed to explore the experience of sleepiness amongst London bus drivers using a highly naturalistic on road study. Whilst other studies have explored the prevalence and causes of sleepiness in this population, this is the first study to investigate sleepiness on a live bus route whilst measuring drivers' sleepiness in both objective and subjective manners.

From the findings it is clear that the amount of sleep obtained by drivers before a shift can vary considerably, with drivers often failing to obtain sufficient sleep before a shift. In the current data the average amount of sleep obtained before shifts was approximately five (morning shift) and six hours (daytime shift), with one participant only obtaining approximately two hours of sleep before the early morning shift. Whilst it was not possible to compare the amount of sleep obtained before each of the recorded shifts to the typical amount of sleep obtained outside of the study period,

506 there were no differences in the amount of sleep obtained before each shift type on days where on-
507 road data was recorded or not, suggesting that this was a typical sleep pattern of drivers during their
508 work schedule. In almost all cases, drivers obtained less than the seven to nine hours of sleep
509 recommended by the National Sleep Foundation (NSF) (Hirshkowitz et al., 2015). The NSF
510 acknowledge that the amount of sleep needed can vary between individuals, however participants
511 in this study obtained less sleep than the amount they reported they needed in order to be
512 sufficiently alert for work. This finding is consistent with previous research. For example, Liendo et
513 al. (2010) found that 50% of surveyed bus drivers obtained less than seven hours sleep before a
514 shift. Similarly our previous survey found that 70% of bus drivers obtained less sleep than they
515 reported needing the night before a shift (Miller et al., 2020) In particular, only obtaining a short
516 sleep before an early morning shift has been observed in other shift workers such as train drivers
517 (Sallinen et al., 2003) and air traffic controllers (Cruz et al., 2000).

518 The short amount of sleep obtained before shifts will subsequently lead to the sleepiness observed
519 whilst driving the bus (for example the increased blink durations during the early morning drive).
520 From a road safety perspective this is concerning, and emphasis should be placed on understanding
521 why this is the case. When considering the results, it should be noted that the any findings of this
522 nature need to be considered in the context of safe systems in which this combination of factors are
523 at play. Participants in the current study reported several reasons for not obtaining enough sleep
524 which demonstrated the combination of personal and work factors which can lead to a driver not
525 obtaining enough sleep. The most common reason reported for not getting enough sleep was going
526 to bed too late. This could be due to personal factors such as lifestyle choices or other
527 commitments, but it could also be due to work and shift patterns such as finishing work late and not
528 having enough time for any post-work responsibilities. This, and the other reasons reported by
529 participants, demonstrates how the combination of personal and work factors can lead to a lack of
530 sleep, which therefore shows that this problem is not just due to drivers failing to schedule enough
531 time for their sleep. This should be considered when interpreting the remainder of the findings in

this study. It is also worth considering that the participants in this study knew they were being monitored throughout the study period. It may be the case that sleepiness may be worse for other drivers who are not being observed.

During the drives, sleepiness was shown to be present particularly during the early morning drive. The prevalence of sleepiness during early morning work has previously been identified amongst shift workers (Kecklund & Åkerstedt, 1995). For example, research into sleepiness amongst shift working train drivers revealed that the prevalence of sleepiness (as measured by KSS) was particularly high during early shifts compared to daytime and evening shifts (Ingre et al., 2004). In the current study, sleepiness during the early morning shift was evident due to the average blink duration being significantly longer than during the daytime drive. Blink duration is a well-established indicator of sleepiness in drivers (Häkkinen et al., 1999), with blink durations greater than 150ms being associated with sleepiness when driving (Fors et al., 2011). Whilst an effect of average blink duration was found, no main effect of the proportion of blinks over 150ms was found. Despite this measure being regularly used in laboratory studies, it may not be as suitable of a measure in applied contexts as we failed to find a difference between conditions as expected. Despite this there were several cases in which individual participants showed long blink durations which could indicate severe sleepiness.

As well as blink duration, 'PERCLOS', defined as the percentage of time that the eyes are 80% closed, is a key metric used in the assessment of sleepiness, and shown to be related to performance (e.g. Jackson et al., 2016). Although linked to sleepiness, the safety implications of eyelid closures and blink durations may depend on the location and time at which the long blink occurs. For example, if a driver is actively driving through a busy city centre longer blink durations may lead to a crash occurring. Whilst this may seem less safety critical when stopped at traffic lights (where the longest blink durations occurred in this research) long blink durations and prolonged periods of the eyes being closed could impact the situational awareness of the driver when they pull away, risking them

557 being unaware of any dynamic changes to the environment (e.g., movements of vulnerable road
558 users).

559 Whilst sleepiness was observed at several points throughout the study, sleepiness was not observed
560 across the entire drive, and differed between drivers. However, any experiences of sleepiness
561 observed in this research suggest a vulnerability within the bus driving system where drivers are not
562 always fully alert. With that it is worth considering the consequences of sleepiness on the road. It is
563 well established that sleepiness is linked to a higher crash risk on the road (Bioulac et al., 2017),
564 however sleepiness can also lead to decrements in cognitive ability by leading to impaired attention
565 and slower reaction times (Williamson et al., 2011). It has also been observed that increased
566 sleepiness when driving due to a lack of sleep can lead to a reduction in hazard perception (Smith et
567 al., 2009), slower braking reaction times (Miyata et al., 2010; Vakulin et al., 2007), an increase in lane
568 crossings (Filtiness et al., 2012), and a higher prevalence of risky driving behaviours (Useche et al.,
569 2018; Watling et al., 2013).

570 Despite the observation of sleepiness through blink durations and sleep obtained, there were very
571 few instances in which drivers self-reported sleepiness through their KSS reports during either drive,
572 as well as few instances when drivers reported sleepiness in the after-drive questionnaire. While it
573 may be possible that some drivers do not have accurate insight into their sleepiness, a recent
574 systematic review and meta-analysis suggests that for the most part drivers are aware of their own
575 sleepiness when driving (Cai et al., 2021). Similarly, other studies of transport shift workers such as
576 train, tram, or truck drivers have shown high levels of sleepiness as measured by KSS (Ingre et al.,
577 2004; Onninen et al., 2021; Pylkkönen et al., 2015). The lack of self-reported sleepiness in the
578 current study may be related to issues in reporting sleepiness during the study. Firstly, despite
579 reassurances that data would be kept private and confidential participants may still have feared any
580 repercussions associated with being sleepy whilst working. Our previous research has shown there is

581 a fear of being disciplined for being sleepy at work amongst London bus drivers (Maynard et al.,
582 2021).

583 Secondly, participants may have experienced difficulties in reporting KSS during the drive either as a
584 result of being unable to perform the secondary task whilst driving, or not being fully familiar with
585 the scale and its associated values. Whilst participants were familiarised with the KSS prior to data
586 collection and had the opportunity to practice reporting their sleepiness using the scale, unlike
587 research conducted in other settings (such as driving simulators where higher KSS levels have been
588 reported compared to on-road driving (Fors et al., 2018; Hallvig et al., 2013)) it was not possible to
589 display the scale throughout the drive to remind participants of the associated values and their
590 meanings.

591 When comparing between the two shifts there was a difference in levels of sleepiness, that is, during
592 the early morning shift, we observed more objective sleepiness (as shown by increased blink
593 durations), whereas we observed higher levels of subjective self-reported sleepiness during the
594 daytime shift (as shown by higher KSS levels). During the morning shifts, the higher levels of
595 objective sleepiness are most likely to be a result of the lack of sleep obtained before the shift and
596 driving during a circadian low. Both factors are important considerations, and it can be difficult to
597 disentangle them to determine a single cause of sleepiness during the early morning shift due to the
598 fact that all but one of the drivers achieved less sleep on the early shift compared to the daytime
599 shift. However, even if the same amount of sleep had been obtained across shifts, drivers on the
600 early morning shift would have faced circadian pressure on their alertness due to the time of day
601 (Åkerstedt & Folkard, 1997).

602 In contrast, during the daytime shift there were higher levels of self-reported sleepiness (KSS).
603 Although drivers may still have experienced sleepiness due to a lack of sleep before their shift, the
604 higher self-reported sleepiness during the daytime shift may be due to higher levels of task related
605 fatigue during this shift, leading to participants reporting higher KSS values. This is supported by the

fact that drivers had a lower heart rate variability on average during the daytime drive, suggesting a higher physiological toll on drivers during this shift (although this was not perceived as being more stressful by the drivers). This higher physiological toll may be caused by a combination of environmental and work factors including higher traffic volume, interactions with passengers, and more radio interactions with bus controllers, all of which have been described as stressful aspects of bus driving (Maynard et al., 2021; Maynard et al., 2022; Tse et al., 2006).

The impact of traffic volume and passenger interactions could explain some of the effects of direction found in the current research, with heart rate variability data suggesting an increased workload when driving towards the city centre. Heart rate variability has been used as a measure of driver stress in previous studies (e.g. Kerautret et al., 2022) with stress being triggered by more hazardous road events. In the current research this effect of direction could be due to the amount of time spent in areas of the route with higher traffic volume and more potential hazards (the city centre) or could be the result of drivers preparing themselves for the increased traffic. Further research may wish to explore this in more detail.

Whilst the comparison between an early morning shift and a daytime shift was based on previous data from London bus drivers, it should be acknowledged that there are other times where drivers may be particularly prone to the effects of sleepiness and fatigue. One example is split shifts in which a driver works half of their shift followed by a longer break before working the second half of their shift. The previous Swedish study demonstrated the prevalence of sleepiness in the second half of a split shift compared to a regular afternoon shift (similar to the daytime shift used in the current research). One shift type less often investigated amongst bus drivers is night shifts. Whilst some research has shown the dangers of sleepiness during nighttime driving amongst car drivers (Hallvig et al., 2014; Sandberg et al., 2011), or truck drivers (Kecklund & Åkerstedt, 1993) less is known about bus driver working night shifts making this an area for future research.

630 On the whole, the results of this paper do suggest that sleepiness is present amongst bus drivers.
631 However, it is worth considering the variance in the experiences of sleepiness between drivers. As
632 seen in Figure 4 all participants had extremely different experiences of sleepiness, and stress, whilst
633 completing both of the drives. Combined with the finding of this on-road study that the drivers
634 experience a mixture of work and personal factors that can lead to not obtaining enough sleep, it
635 can be said that sleepiness is a personal experience which varies between and within individuals.
636 Similarly, baseline levels of sleepiness will differ between drivers both when they are working and
637 driving the bus, and on non-driving days. Differences in relation to sensitivity to sleepiness have
638 been previously reported, both in terms of susceptibility, and the level of impairment experienced.
639 For example, Van Dongen et al. (2004) reported substantial inter-individual variation in impairments
640 to performance following sleep loss. As summarised in Anund and Dahlman (2023) factors such as
641 chronotype, age, gender, medical conditions, and personality factors have also shown differences in
642 terms of tolerance and vulnerability to sleepiness.

643 With regards to age, whilst the current study found no significant correlations between age and
644 sleepiness the relationship is more complicated. In general, there is evidence that older drivers are
645 less vulnerable to sleep loss and subsequently sleep related driving impairments compared to
646 younger drivers (Scarpelli et al., 2021). However recent evidence suggests that younger bus drivers
647 (those under 30) are less likely to be involved in crashes compared to older bus drivers but are more
648 likely to be involved in a serious crash (Barabino et al., 2024). This could be due to a number of
649 factors such as experience or risk taking, in addition to the potential role of sleepiness. Whilst it is
650 not possible to explore the impact of age on sleepiness and crash risk in the current research,
651 further work should explore this whilst considering the complex interplay between age and
652 sleepiness, as well as the variety of other factors which contribute to crash risk (see Barabino et al.,
653 2024; Huang et al., 2021).

As well as differences between individuals, there are also day-to-day variations or intra-individual differences, such as poor sleep, life events, illness, diet, caffeine and alcohol intake, which can impact an individual's sleepiness. Individual differences are therefore an important consideration in terms of sleepiness management, as they can impact not only the detection or prediction of sleepiness, but also the effectiveness and choice of countermeasures.

Consequently, a systems approach for mitigating sleepiness and fatigue is needed. Firstly, the individual differences in the causes and presence of sleepiness should be considered meaning that interventions should consider the great differences between drivers. Additionally, interventions should consider the multifaceted nature of driver sleepiness. Simply implementing one solution, for example relying on fatigue detection through use of ocular measures, which is frequently used within transportation, may not be successful as it only addresses one aspect of driver sleepiness without considering the multifaceted aspect of this problem. There is therefore a need for a more holistic approach to detecting and managing fatigue, due to the individual differences experienced in relation to sleep, sleepiness and sleepiness indicators. As such, fatigue management needs to be dynamic to best match the causes of sleepiness that drivers experience.

4.1. Limitations and practical challenges in the current research

One final point to consider in relation to the current research are the limitations and practical challenges associated with running this study. As previously described in the introduction, this is the first study to investigate bus driver sleepiness in this highly naturalistic setting using live bus routes and drivers' existing shift schedules, as well as recording sleep for multiple days during the study period. Due to the highly naturalistic nature of this research, it was not possible to exert control over factors such as traffic or other work-related or personal factors between the early morning and daytime shift. However, this is highly reflective of daily life as a bus driver.

677 A second complexity was that during the recording of data on live bus routes, the priority of the
678 drivers and their operating company was to ensure that the buses continued to run on time and that
679 drivers completed their shift as normal and in safety. This meant that there were cases of missing
680 data, particularly for subjective reports such as KSS and SUS which could explain the relatively low
681 KSS and SUS scores recorded, in the current research where a balanced approach had to be taken
682 between recording all the required data in cases where equipment was temporarily broken or
683 unavailable, or recording partial data to ensure the bus ran on time. The relative low levels of self-
684 reported sleepiness and stress could also be an effect of high cognitive load masking the effect of
685 sleepiness. KSS is a sleepiness scale mostly used in situations where the drivers' sleepiness is
686 manipulated using time of the day, hours slept and hours being awake in combination with driving
687 under task related fatigue due to underload (May & Baldwin, 2009). Addressing the lack of studies in
688 the realistic more complex driving situations, as in this city bus driving context, was one of the
689 strengths of the study; at the same time this is also a limitation when it comes to existing tools to
690 measure sleepiness in such situations. Here future research and developments are needed.

691 One difficulty associated with collecting this data was the initial recruitment of participants working
692 on a specific bus route with a particular shift schedule. In order to ensure that the data obtained was
693 as true to life as possible, it was important to avoid changing drivers' schedules which meant that a
694 limited number of drivers were eligible to take part in the research. In addition, as this was a multi-
695 part study drivers had to be willing to participate in all aspects of the study and for its full duration.
696 As our previous work has shown, there is often a fear of reporting sleepiness or being seen as sleepy
697 at work amongst bus drivers (Maynard et al., 2021). However, conducting the research in a real-
698 world setting required the involvement of the employer, otherwise it would not have been possible
699 to instrument the buses. Even when working with the employer it was still only possible to
700 instrument a small number of buses, which again can influence the number of drivers able to take
701 part in the research. This was therefore a necessary compromise that potentially dissuaded some

drivers from participating. As a result, extra caution was taken to reassure drivers that results would be anonymised and not shared with employers.

These factors led to a small sample of 16 drivers taking part in the research. Whilst this may have meant that the current study was underpowered to detect some effects, the main hypothesised effects were found with medium effect sizes. This sample size was also similar to a previous on-road study in Sweden which tested a total of 18 drivers (Anund et al., 2018). However, the current sample does only represent a small proportion of all London bus drivers (approximately 25,000 at the time of data collection) so the experience of sleepiness will differ between drivers. These challenges should be considered in future research which may wish to test a larger sample of drivers across multiple bus routes. Despite the sample limitations, the smaller sample size did allow us to obtain more in-depth data from a small number of drivers which did allow us to look at individual differences.

The challenges associated with recruiting drivers and instrumenting buses also meant that the study was only designed to collect data across one bus route. Whilst this was one of the longer routes in London and covered a mixture of different driving environments it should be acknowledged that different bus routes may lead to different experiences of sleepiness and stress on the road.

However, previous research has shown that the experience of sleepiness is a common occurrence amongst London bus drivers (Maynard et al., 2021; Miller et al., 2020) which suggests that similar findings may be observed amongst bus drivers working other routes with similar shift patterns.

Similarly, research in Sweden has shown similar results amongst drivers working split-shifts (Anund et al., 2018). Future research may wish to extend the current findings by investigating bus driver sleepiness across different bus routes in different countries, the differences between city bus drivers and drivers across different road environments (such as rural bus routes), as well as comparing the effects of sleepiness across different routes and areas within the same bus network. In addition, further work may wish to consider the potential impact of working other times where sleepiness

may be highly prevalent such as night shifts. When conducting further research consideration should be placed on not interrupting drivers' regular working schedules, ensuring drivers are comfortable taking part in such research, and working closely with bus companies in order to access drivers and a sufficient number of buses to be instrumented.

Despite these complexities, the data obtained in the current study still provides a very good understanding of the experience of sleepiness and stress amongst a group of London bus drivers during their normal work pattern. Further work may wish to expand these findings by conducting research with a greater number of drivers outside of London, or by using a more longitudinal method.

4.2. Conclusions

This study was designed to examine fatigue in normal driving operations using self-report, physiological, and vehicle recording metrics. This design allowed the investigation of specific research questions during service delivery, providing a real-time on-road picture of bus driver fatigue. The study was successful in not compromising the delivery of service for the operator and is the first of its kind to investigate bus driver sleepiness in such an in-depth manner.

The research questions addressed by the study were: 1. What is the extent and nature of fatigue in London bus drivers? 2. What are the key causes of fatigue amongst London bus drivers? and 3. What solutions should be implemented or trialled to reduce fatigue and the risk of associated incidents?

The results demonstrate that sleepiness is present amongst bus drivers when completing their regular shifts as observed through both objective and subjective measures of sleepiness. As hypothesised, we observed higher levels of objective sleepiness during the early morning drive as well as higher levels of stress during the daytime drive (however participants self-reported greater sleepiness during the daytime drive likely as a result of the increased stress and task-related fatigue). Whilst sleepiness was common in this study, it should be acknowledged that the experience of

751 sleepiness, including differences in the amount of sleep needed and sleep obtained, varied between
752 individuals, supporting the idea of individual differences in the experience of sleepiness.

753 The reasons for sleepiness were found to be a combination of work and personal factors, including
754 factors such as shift patterns, working hours, traffic, and personal commitments outside of work.
755 This again will differ between individuals.

756 Due to this combination of factors, it is important to consider bus driver sleepiness within this wider
757 system as opposed to simply placing the onus on the drivers themselves. Instead, we should enable
758 the drivers to take action to reduce their sleepiness within a wider context of their work
759 environment. This research highlights the need to be aware of sleepiness amongst bus drivers, as
760 well as the need to manage and reduce sleepiness where possible within a wider safety system.

761 The key recommendations arising from the study include the highlighting of the importance of
762 educating drivers on the importance of good quality sleep, and promoting an open culture in which
763 drivers and those around them are encouraged to talk about fatigue whilst enabling them to report
764 fatigue without fear of discipline. It is also suggested that changes could be made to scheduling, such
765 as reducing the number of early morning shifts. With regard to work conditions, it was found that
766 there is a requirement to ensure drivers have the appropriate facilities to rest during or before
767 shifts. Lastly, the study recommends the introduction of general health-based interventions to
768 improve overall health, reduce driver stress and screen those at high risk of sleep disorders such as
769 Obstructive Sleep Apnoea (OSA).

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