Stress, fatigue and inattention amongst city bus drivers – an explorative study on real roads within the ADAS&ME project

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Abstract: Knowledge about normal glance behaviour and typical stress and fatigue levels amongst city bus drivers is very sparse. We therefore conducted an exploratory pre-study with 15 participants during an actual shift in real traffic with passengers. The aim was to gain knowledge about stress, fatigue and glance behaviour during normal operation of a bus, with the subsequent goal to gather data to facilitate upcoming work on driver state detection algorithms targeting the transfer of control between the driver and an autonomous bus. Data collected during the trials include eye tracking, physiology (electrocardiogram, electrooculogram), subjective ratings (sleepiness and stress) and video (driver and road ahead). Lessons learned includes that driving a bus in an urban environment requires frequent sampling of peripheral visual information (why one-camera eye trackers will not work, and why road centre-based distraction detection algorithms will fail) and that physiological data requires personalised algorithms. Regarding the bus drivers' working situation, fatigue and stress levels were generally low, but increased levels of stress and sleepiness existed even in an exploratory experiment like this without any manipulation.

1. Introduction

The goal of doubling travels with public transportation by 2020 requires more efficient operation, and already now working as a bus driver involves much more than just driving the bus. The responsibilities to control where to go, keep track of the timetable, make sure that the bus is on time, oversee and support ticketing, communicate with the operator and interact with the passengers can be overwhelming [1]. On top of that, the bus driver occupation is associated with negative physiological, physical and psychosocial factors related to driver's health [2]. Many of these factors are expected to become more severe in the future and lead to an even more stressful work environment. Despite this awareness, very little research has been conducted to investigate the levels of stress, sleepiness and inattention amongst city bus drivers during an ordinary day at work. In this exploratory study, we aim to investigate city bus drivers' normal fluctuations in stress and fatigue levels, along with visual behaviour, while driving a specific bus route in real traffic with passengers present in the bus.

Driver fatigue in general has received increased attention during recent years and is now considered to be a major contributor to approximately 15 – 30% of all crashes [3-5]. The main cause of driver fatigue is sleepiness due to sleep loss, being awake for too long, and driving during the circadian low [6]. These factors are amplified by obstructive sleep apnoea, a problem shown to be pronounced in the public transport sector [7]. Also, work-related factors such as stress [8, 9] and shift work [10] contribute to driver fatigue. In addition, it is important to consider the type of task [11, 12], as both cognitive underload and overload contribute to the development of fatigue. City bus drivers in particular face work in a stressful and draining work environment on a daily basis, exposing them to the serious risk of driver fatigue [13].

Driver stress is associated with frustration, irritation, negative mood and aggressive driving behaviours such as speeding violations, tailgating, and involvement in minor traffic accidents, in particular under situations of time pressure [14-17]. Social stress, such as personal tragedies or conflicts with significant others, have been estimated to increase the odds of a fatal road accident by a factor of five [18]. These results, from car drivers, are not easily generalised to bus drivers since they must safeguard passenger safety and indeed their own job [2]. That said, city bus driving has been identified as one of the most stressful occupations [19] due to mental and physical exhaustion [20] caused by conflicting pressures to drive safely while maintaining tight schedules in an external environment that the drivers have little control over [21]. Note that stress is a normal physiological response to adapt, cope or adjust with the situation. It is only when driving is interpreted as demanding or dangerous that stress manifests itself as negative, for example in terms of anxiety or worry [22], or as increased heart rate and blood pressure [23].

Driver distraction and inattention poses a significant safety problem both in the personal and public transport sector. In bus driving, inattention and fatigue are considered to be the most common causes of road crashes [24], and crash analyses have particularly highlighted "inattention", "failure to yield" and "not in lane" as causes of fatal city bus accidents [25]. The sources of distraction causing accidents include those that arise from the driving task itself, and those that derive from the additional requirements associated with bus operation, such as passenger and ticketing-related incidents [1]. The most distracting activities are passenger-related and beyond the control of the bus driver [26].

This study is part of the H2020 project ADAS&ME (Adaptive ADAS to support incapacitated drivers mitigate effectively risks through tailor made HMI under automation). ADAS&Me include seven use cases, one of them addressing bus drivers, with the aim to reduce stress and fatigue by automating the docking procedure at the bus stop. This particular scenario has been highlighted by bus drivers to be very stressful since they have to keep track of the passengers, watch out for vulnerable road users outside the bus, and manoeuvre the bus in a smooth and precise manner [27]. By automating the docking procedure, a procedure that requires the driver to be highly attentive, many risky actions related to passenger unloading, pedestrians crossing near bus stops, and driving off from a stop before passengers have time to get seated [24, 28, 29], can be avoided. When transferring the control from the bus to the driver after departing the bus stop, it is necessary that the driver is fit to take back the driving responsibilities. The main focus of the bus use case in ADAS&Me is to design driver monitoring algorithms that ensures that this is the case. If the driver is not ready to take back the control, the bus will initiate a safe stop procedure.

When starting the algorithm design work in ADAS&Me, it was noticed that very little research was available about typical stress and fatigue levels amongst city bus drivers, except for retrospective self-ratings and questionnaires. Neither could we find any information about typical glance behaviour amongst city bus drivers. We therefore found it necessary to carry out an exploratory data collection to get a better understanding of the stress and fatigue levels that can be expected in city bus drivers' during a normal day's work. The aim of this paper is to describe the results from this pre-study. Given the intended applications of algorithm development and automated docking at bus stops, special focus will be devoted to details useful in the upcoming algorithm development work and to driver behaviour in the vicinity of bus stops.

2. Material and methods

2.1. Participants

In total 15 drivers (2 females/13 males, mean age 41±12 years, 11.6 ± 8.2 years of bus driving experience) were involved in the experiment. They had a BMI of 25.9 ± 3.6 and 13 out of 15 drivers reported being satisfied with their working hours. All participants were recruited from Transdev, the local bus operator in the city of Linköping. The bus drivers received a monetary compensation of about 100 Euros.

The study was approved by the regional Ethics committee in Linköping (Dnr 2017/278-31) and all drivers signed an informed consent form.

2.2. Preparations

Sleep diaries and actigraphy (ActiGraph LLC, Pensacola, FL, US) was collected for two days before the experiment day to keep track of the drivers sleep/wake history. The Actigraph was sent to the drivers together with a background questionnaire and the sleep diaries one week before the experiment day. The intention with the sleep diaries and the Actigraphs was to have a possibility to go back and check if potential outliers could be explained by a deviating sleep history.

2.3. Data collection

The bus was equipped with a three-camera head and eye tracking system (Smart Eye Pro ver. 7.0, SmartEye AB, Gothenburg, Sweden), tuned to give high accuracy in the forward gaze direction at a rate of 60 Hz. The eye tracker was connected to a model of the bus, allowing analyses of the objects in the cockpit attracting the driver's gaze. Gaze data points were consequently clustered into glances towards the following targets (Fig. 1): 1–front window, excluding the road centre area, 2–road centre, defined as a circle with a radius of 8° centred on the modal point of the gaze distribution, 3–left mirror, 4–right mirror, 5–C90 onboard computer, 6–instrument cluster including speedometer, 7–communication radio, 8–FleeTech system, 9–ticket machine, 10–unknown, and 11–lost tracking. The eye tracking system provides a quality indicator in the range from 0–1, based on the contrast between the edge of the iris and the sclera. All samples with gaze quality below 0.2 were set to 'lost tracking' to remove unreliable data. In the current dataset, 34.4±9.9 % of the data were set to 'lost tracking'. The high percentage of lost tracking is likely due to extreme gaze directions outside the cameras' coverage in the present camera setup, especially near bus stops, a large head box (compared to cars), and possibly also larger windows and less shadow, giving rise to more squinting.

Fig. 1. *The cockpit of the bus, including the targets used in the glance analyses.*

Physiological data were acquired with a sampling rate of 256 Hz by a portable digital recording system (Vitaport 2, Temec Instruments BV, the Netherlands). This included an electrooculogram (EOG, measured vertically and horizontally across the eyes) and an electrocardiogram (ECG, lead II). The electrodes used were of the disposable Ag/AgCl type. Electrodermal activity (EDA) was also recorded via a wearable wrist device (Empatica E4, Empatica Inc., Italy).

An observer accompanied the bus driver throughout the experiment. The observer also asked the driver to rate his/her subjective sleepiness level on the Karolinska sleepiness scale (KSS) [30] and stress level on the Stockholm University stress scale (SUS) [31] every fifth minute. These are anchored scales with nine levels, KSS: 1–extremely alert, 3–alert, 5–neither alert nor sleepy, 7–sleepy, no effort to stay awake, and 9–very sleepy, great effort to keep awake, fighting sleep, and SUS: 1–very low stress (very calm and relaxed), 3–low stress (calm and relaxed), 5–neither low nor high stress, 7–high stress (high tension and pressure), 9–high stress (very high tension and pressure).

Kinematics and GPS data were recorded with a data logger that also stored video of the forward view and of the driver (Video VBOX Pro, Racelogic, Buckingham, UK). The data logger was synchronized with the physiological recording system and the eye tracker.

2.4. Design

The design of the experiment was exploratory, and no experimental manipulation of the stress or sleepiness levels of the driver was made. Instead, the drivers' normal fluctuations in stress and sleepiness levels were of interest. This means that except for the electrodes and the measurement equipment, there is no difference between the experiment and an ordinary day at work. The study was run in the medium sized city of Linköping (about 160000 inhabitants). The specific route that was chosen for the test was selected since it has, for a medium sized city, a tight time schedule, since most of the route is on city roads, due to the large number of passengers, and since there are many bus stops along the route. The data collection was done during a normal working day while driving the bus with real passengers. Data from two drivers were collected each day, during the morning shift and during the afternoon shift, respectively. After the shift, the measurement equipment and electrodes were removed, and the driver answered a final questionnaire about his/her experiences during the shift.

The schedule for carrying out the experiment was very tight since extended preparations would interfere with the rest and drive time regulations. In total, we had 20 minutes to inform the participants, attach the electrodes, calibrate the eye tracker and start the data logger. After the trial, we had 4 minutes to power down the system, remove the electrodes, etc.

2.5. Data pre-processing

Blink durations, which is a commonly used measure of sleepiness and fatigue [32], were extracted from the EOG to complement the subjective KSS ratings. Blinks were extracted using an automatic blink detection algorithm based on derivatives and thresholding [33]. To reduce problems with concurrence of eye movements and blinks, the blink duration was calculated at half the amplitude of the upswing and the downswing of each blink and defined as the time elapsed between the two.

Heart rate variability (HRV) metrics and EDA are commonly used measures of driver stress [34]. Heart beats were extracted from the ECG using an automatic detection algorithm based on filter banks [35]. Guided by the meta-analysis by Castaldo et al. [36], three HRV metrics were chosen due to their relation to acute mental stress; the power spectrum density in the HF band (0.15–0.4 Hz), the LF/HF ratio (where LF is the power in the 0.04–0.15 Hz band), and the square root of the mean squared differences between successive heart beats (RMSSD).

The EDA signal was decomposed into a tonic and a phasic component using Ledalab [37], where the phasic component was used as yet another indicator of driver stress.

Table 1: Sleepiness ratings where each value corresponds to the feeling during the past five minutes.

KSS	Frequency	Percentage
1	60	38.0
2	39	24.7
3	41	25.9
4	13	8.2
5	5	3.2
6	0	0.0
7	0	0.0
8	0	0.0
9	0	0.0
Total	158	38.0

The mean and the 90th percentile blink durations as well as the HRV metrics were calculated in a sliding window with 20 seconds overlap and a width of 5 minutes.

2.6. Analysis

Most analyses were based on descriptive statics due to the exploratory nature of the study. *Fatigue indicators* were investigated as a function of time on task, with the expectation that the drivers would become more fatigued over time. *Stress levels* were investigated as a function of how delayed the bus was compared to the time table, and also near bus stops (mean value in the region ± 100 meters from the bus stop) versus in between bus stops. This was analysed with a mixed model analysis of variance (ANOVA) with the fixed factor bus stop versus driving, and the random factors participant and bus stop. *Inattention*, or rather glance behaviour, was analysed as glance frequencies and glance durations throughout the trip. The distribution of glances to the coded glance targets was also analysed near the bus stops.

3. Results

3.1. Sleepiness

On average the bus drivers reported low levels of subjective sleepiness while driving, see Table 1. Two drivers

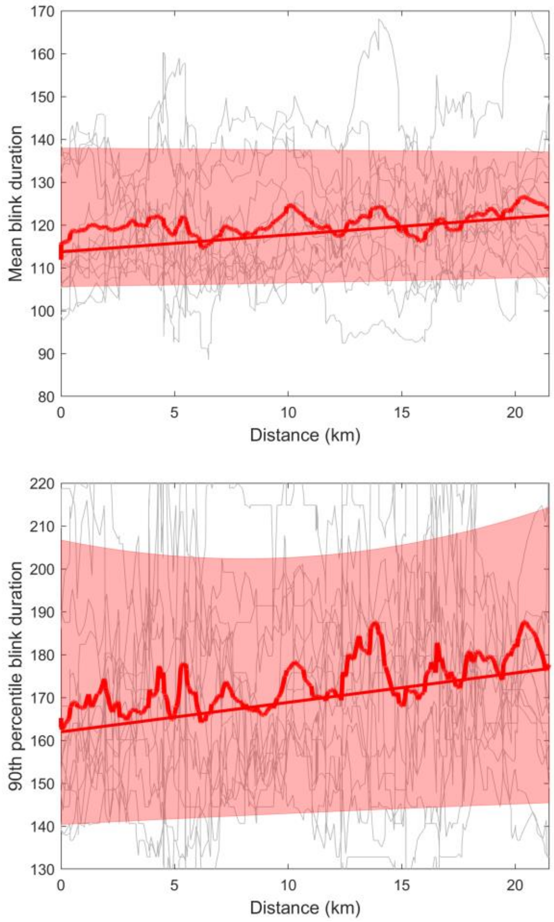

Fig. 2. *Mean and 90th percentile blink durations as a function of distance driven. The grey curves are from individual participants, the red bold lines are the mean across the grey curves and a fitted regression line. The transparent red area is the 10th to 90th quantile regression lines of order 2.*

had mean blink durations exceeding 150 ms in five of the 5-minute segments. This is a clear indication of sleepiness. There was a slight trend towards longer mean blink durations in the end of the drive (median regression line with slope 0.40 and intercept 113.74), see Fig. 2. This trend was stronger when only considering the longest blinks in each 5-minute segment (median regression line with slope 0.69, intercept 161.99), see Fig. 2. In total 5 out of 15 bus drivers reported being sleepy during the data collection. They justified this by: went to bed too late, early morning start, poor sleep the night before, just woke up, too much time waiting at red lights.

3.2. Stress

On average the bus drivers reported low levels of stress while driving, see Table 2. However, some individuals reported high levels at some specific situations even though they were not manipulated. Four out of 15 bus drivers reported high levels of stress in the post-questionnaires. They justified this by: Lots of passengers, problems and misunderstandings, being late, dense traffic, and passengers shouting and talking loudly.

It was hypothesised that higher levels of stress would be reached at bus stops compared to while driving between bus stops. However, the mixed-model ANOVA showed no significant main effects on any of the HRV metrics at the 1 % significance level. There was, however, large individual differences and differences between the various bus stops (Table 3). There was an effect of bus stop versus driving on phasic EDA, but since this finding was not supported by the HRV metrics, this is probably a spurious result, or perhaps an effect of increased sweating caused by manoeuvring the bus near the bus stop.

When comparing HRV metrics versus how delayed the bus was compared to the time table, it was noticed that HF, and to some extent also RMSSD, was reduced with larger delays, see Fig. 3. Above all, the variation in the HF and RMSSD values decreased with the delay, and large delays were characterised by an absence of higher values.

3.3. Inattention

In total one bus driver reported being inattentive. This was justified by: high stress level and misallocated focus on traffic-irrelevant issues.

The glance behaviour data didn't show unexpectadly long glances to any of the in-vehicle systems, table 4 and Fig. 4. The low frequency of glances to the right mirror is probably due to the large head movements, which lead to the loss of visibility of the eye in the used camera setup. Eyes off road glances had a mean duration of 0.7 seconds and a 95th percentile duration of 2.3 seconds, which is comparable to what is typically found in car driving.

Table 2: Stress ratings where each value corresponds to the feeling during the past five minutes.

SUS	Frequency	Percentage
1	59	39.9
2	54	34.0
3	14	8.8
4	12	7.5
5	8	5.0
6	8	5.0
7	3	1.9
8	1	0.6
9	0	0.0
Total	159	100

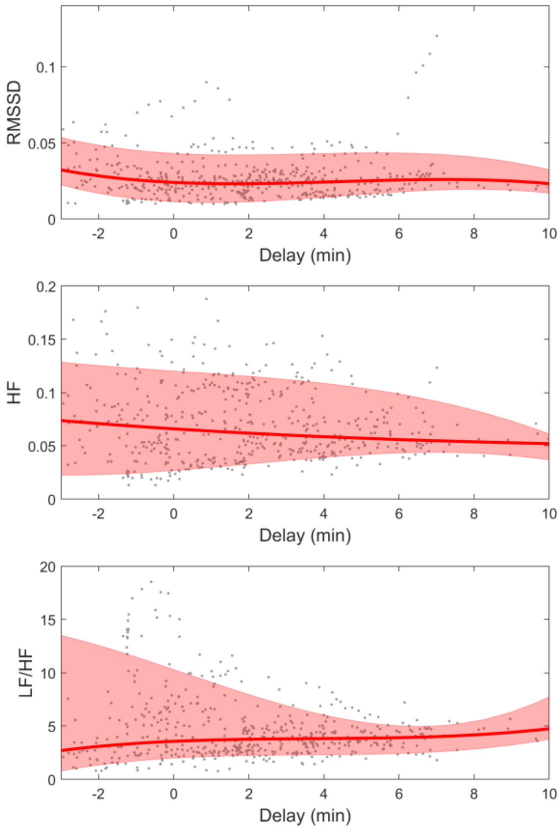

Fig. 3. *HRV metrics plotted as a function of how delayed the bus is compared to the time table. The grey dots are individual HRV metrics per 5-minute segment along the route, the red bold lines and the red shaded areas are the median quantile regression line and the 10^{th} to 90^{th} quantile regression area (order 3).*

Table 4: Glance duration and glance frequency. For 'unknown' and 'no tracking', a "glance" is determined as the "gap" between two known glances.

	Number of glances per km	Mean glance duration (ms)	95th percentile glance duration (ms)
Left mirror	6.0	396	1034
Right mirror	0.6	158	404
C90	3.4	266	875
Cluster	4.3	304	700
Com radio	0.8	282	904
FleeTech	1.5	212	500
Ticket machine	1.7	167	517
Unknown	23.6	347	1084
No tracking	48.4	569	1967
Eyes off road	56.3	731	2317

Glance behaviour while approaching the bus stop showed that when the bus got closer to the bus stop, the drivers looked less in the road centre region and gradually shifted their focus towards the periphery. This visual scanning behaviour is first seen as an increase in the gaze distribution towards the rest of the windscreen (about 5 seconds before arriving at the bus stop), see Fig. 5. When getting even closer to the bus stop, both road centre and windscreen glances are reduced further, and the drivers are only looking in these regions for about 20% of the time. At the same time, the percentage of lost tracking and glances towards unknown glance targets increased. This is probably because the drivers are focusing their attention to vulnerable road users outside the bus and towards the passengers who are lining up to get onboard. The reason why this is coded as no tracking is likely because the gaze direction is outside the coverage of the eye tracking cameras.

Glance behaviour when leaving the bus stop is similar to when approaching the bus stop, but in reversed order. The percentage of road centre and windscreen glances are continuously increasing until they together reach a level of about 75%. The percentage of glances to the left mirror

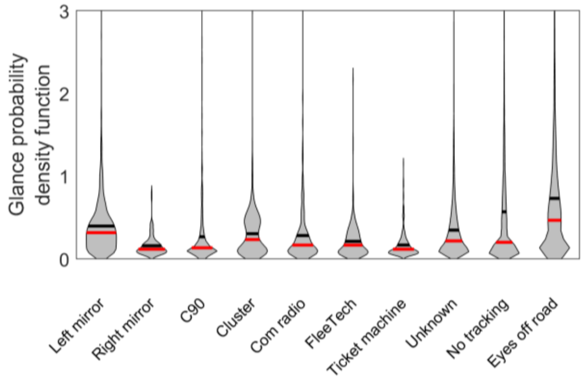

Fig. 4. Violin plot showing the probability density functions when looking at different glance targets.

increases during the first five seconds after departure, showing that the drivers are checking for traffic from behind before they depart.

4. Discussion

The bus drivers in this exploratory study of a normal driving shift generally showed low levels of fatigue and stress. This was expected since they followed their ordinary duty roster, without manipulation of stress and fatigue levels. Perhaps the most interesting outcomes from this study concerns methodological aspects and the observed behaviour that couldn't be measured, as outlined below.

Subjective sleepiness ratings based on KSS is a trusted estimate of sleepiness that is as close to a gold standard as we, today, can get. Yet, the bus drivers reported suspiciously low levels of sleepiness during the data collection, much lower levels than is normally seen during alert conditions. The most frequent rating was KSS=1, a condition that essentially means hyperalert, something that only occurs for short lapses. The reasons for this are not known, but it may be because they didn't want to report high levels of stress and sleepiness in front of the passengers. Another reason may be that they hadn't fully understood the rating scale. KSS is a nonlinear scale where the default state should be around 4–5, where lower levels are essentially different levels of alert. Information about the scales were sent to the drivers

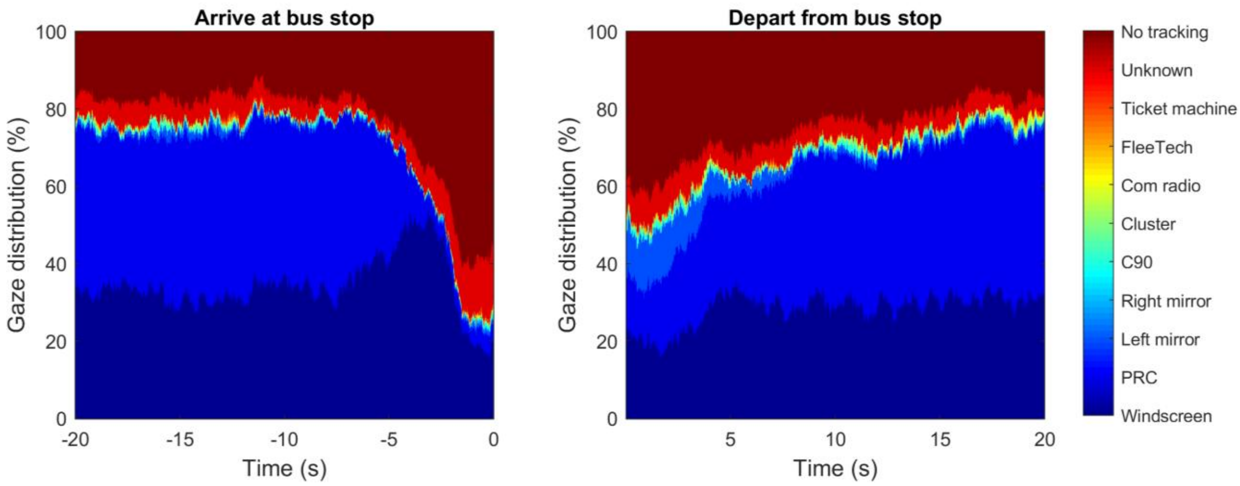

Fig. 5. Distribution of glances to different targets over time, during the last 20 seconds before stopping at the bus stop and during the first 20 seconds after departing from the bus stop.

beforehand, but it seems like not all of them had read the instructions thoroughly enough before arrival. However, despite the low self-reported values, some drivers reported high levels of sleepiness in the post-questionnaires, some drivers experienced mean blink durations above 150 ms, and the 90th percentile blink durations showed a clear time on task effect. This supports the explanation that the drivers did not find it comfortable to report their experience while driving.

The subjective stress ratings were also very low, just as the sleepiness ratings, and again, the post-questionnaires revealed that several (4 out of 15) bus drivers had experienced high levels of stress. This was supported by the HRV metrics that indicated decreasing RMSSD, decreasing HF, and slightly increasing LF/HF for larger delays compared to the time table, all indicating elevated stress levels. Again, this indicates the drivers did not find it comfortable to report their experience while driving. This problem with the subjective ratings is difficult to get around. Verbal ratings will always be heard by the passengers, and even with an ethical approval, most bus companies will not allow their drivers to enter the ratings on a tablet or similar device while driving due to company policies.

The most interesting results from the glance behaviour analyses comes from what is inferred from 'lost tracking'. From Fig. 5, it is painfully obvious how important context is when analysing visual behaviour, especially in complex environments such as in the city. Available real-time driver distraction detection algorithms typically set up a fixed 'on-road'-region where the driver is supposed to look most of the time. When looking outside this region for too often or for too long, the driver is considered distracted [38]. In Fig. 5, one can see that the 'on-road'-region must be dynamic, and in this case with the bus stop, this region should represent the bus stop and the vulnerable road users surrounding it rather than the road ahead. The problem is that there is no gaze data available in this direction. In future studies a fourth camera positioned close to the right A-pillar would be beneficial to track right-side glances. Also, ideally, there should not be one but several regions, that change adaptively with the road environment and surrounding road users [39]. To operationalise such an approach, the eye tracking data needs to be fused with environmental sensing. That said, it is clear that automating the docking procedure will help relieve the bus driver in a situation where many targets in multiple locations has to be attended simultaneously.

An observation made during the exploratory analyses was that the self-ratings as well as the physiological measures and the glance data showed variations due to the environment. This indicates that it is important to consider multiple factors simultaneously, and not just multiple physiological indicators, but also external factors (environment, traffic complexity, route, scheduling, passengers etc.) as well as individual aspects (driver traits, health status, family situation etc.), when trying to understand and predict changes in sleepiness, stress and visual attention. Such research has been initiated to get a better picture of the causes of driver sleepiness [40], stress [41] and inattention [39], but mostly on a theoretical level, and not taking the operator's demands into account. There is also very little research on the interaction between multiple simultaneous driver states. Research in this direction is laborious and requires costly experiments, but it may be the only way forward when designing the driver monitoring systems that will (have to be) an integral part of the intermediate steps towards full automation.

5. Conclusions

The results show that even without manipulation there are epochs of sleepiness and stress in some individuals at a normal bus route during daytime.

Countermeasures to make sure this is not the case is most truly helpful for the drivers.

Algorithms that estimate the driver's state based on physiological data should be personalised.

Driver state detection algorithms, especially for stress and inattention, must take the traffic environment and surrounding road users into account.

6. Acknowledgments

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