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Mind the gap: drivers underestimate the impact of the behaviour of other traffic on their workload

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Abstract

This study examines the effect of traffic demand on driver workload by varying a range of characteristics of traffic behaviour, in particular focusing on the influence of a lane change performed by a neighbouring vehicle. To examine drivers' ability to manage their own workload in these traffic situations, a self-initiated, surrogate mobile phone task was presented to them, to coincide with changes in traffic demand. Results showed that whilst participants delayed the initiation of the task when the lane change was performed in close proximity to them, the delay was insufficient to mitigate the effects of the increased workload, leading to task errors. This was attributed to driver's willingness to engage in secondary tasks, even though their (self-reported) workload had not returned to baseline levels. The minimum workload recovery period was calculated as being 12 seconds after the onset of the adjacent vehicle's manoeuvre, and this has implications for the design of workload managers.

Keywords: Driving; Workload; Lane change; Secondary task; Demand

1 Introduction

Drivers spend a significant amount of time interacting with the surrounding traffic; the amount of traffic not only influences the visual demand imposed on drivers but also to some degree the behaviour of the drivers themselves (Zaidel, 1992). The traffic environment represents an important and commonly experienced social space that constitutes individuals with varying driving behaviour traits, who interact with one another within a set of written and unwritten rules. Driving culture and hence traffic safety culture is represented by these collective behaviours of other drivers, creating a direct interaction and impact on an individual driver (Ward and Özkan, 2014). For an individual driver, their skills and experience play important roles in structuring expectations, enabling them to formulate hypotheses about the adjustment that other road users may force them to make (Saad et al., 1999). Wilde (1976) provides an extensive review of social interaction patterns, which places various social factors in perspective and discusses how they interact with other factors in driving. For example the presence of other drivers, especially when driving in heavy traffic, may increase demand (e.g. Verwey, 1993; 2000). Other factors include expectations about the behaviour of other road users in terms of obeying rules of the road, and communication between drivers through use of signalling lane changes, as well as the social aspect of invasion of one's personal space, particularly when other drivers follow or pull-in too closely. Through extensive learning and exposure within this rather complex social environment, drivers develop their own expectations for themselves and others following their experience of typical speed, volume, flow and style of traffic within their area. One of those expectations that develops over time is their own desired proximity to other vehicles.

Previous research has found that drivers alter their space preference. For example, in congested conditions, drivers tolerate reduced personal space (Baum and Greenberg, 1975). Traffic congestion and surrounding traffic behaviour alters interpretations and reactions of drivers (for example, increasing driver stress, revenge motivations and aggressions). Fraine et al. (2007) suggested that some drivers identified cutting in and tailgating as a "violation of personal space". With increasing uncertainty in road situations, drivers sample the road ahead more intensely due to increasing driving demand (Senders and Kirsofferson, 1966). To date, little research has examined the temporal fluctuations in workload caused by other traffic, by systematically varying its presence and behaviour. The study reported here attempts to do this, and in addition presents a secondary task to explore how drivers manage their own workload.

Workload can be characterised as a mental construct that relates to attentional demand (Kantowitz, 1987; Wickens 1992) to explain the inability of human operators to cope with the requirements of a task (Gopher and Braune, 1984). As workload is related to subjective task difficulty and thus related to effort invested, workload measurement can be employed to characterise effort invested in the performance of the task (De Waard, 1996). While drivers do not passively respond to workload demands that are imposed on them (Adams et al., 1995; Raby and Wickens, 1994; Tulga and Sheridan, 1980), and actively manage their own workload by shedding or delaying tasks, they sometimes fail in choosing an appropriate workload level suitable for themselves. Drivers are often viewed as active operators, who are not only capable of assessing their own momentary load but also play an active role in the initiation and management of distracting in-vehicle activities (Lee and Strayer, 2004). However, some studies have also shown that, despite drivers being aware of increases in demand from the roadway, they still choose to engage in the secondary tasks (Horrey and Lesch, 2009) in these high workload conditions.

Initiating secondary tasks such as the use of a mobile phone during high workload conditions may result in perceptual and decisional impairment due to the division of drivers' attention between different sensory modalities (Brown et al., 1969). Some research shows that hands-free phones are equally as distracting as handheld one (e.g. Hendrick and Switzer, 2007) – the act of being involved in a conversation while driving is distracting and can have a detrimental effect on drivers in demanding situations as it detracts a driver's attention away from the primary task of driving (Strayer et al., 2005). This has been found to be particularly so when the conversation has a visual component; Briggs et al. (2016) report that drivers who were distracted by imagery tasks (such as "a cube has six sides") demonstrated decreased hazard perception and increased response times compared to those engaged in non-imagery task (America has 51 states). Almor (2008) has shown that the act of speaking increases the level of interruption with performing a visual task by as much as four times relative to listening-only conditions. Thus if there is a need to perform a response, perception and decision-making abilities could be critically impaired by drivers having to switch their attention between eyes and ears (Spence et al., 2001).

Studies have showed that, even though using a hands-free mobile phone during driving increases subjective workload (Parkes et al. 1993; Alm and Nilsson, 1994) and heart rate (Brookhuis et al., 1991), drivers are not dissuaded from engaging in a series of in-vehicle activities even in challenging and traffic-heavy driving situations (Lerner and Boyd, 2005). Similarly, a questionnaire survey conducted by Lansdown (2012) found that over 30% of surveyed drivers used a hands-free mobile phone during a typical week and would still attempt to use it despite being aware it was distracting. Kidd et al. (2016) have recently published data that suggests that drivers modulate their secondary task activities based on the perceived roadway or driving demand. However, they did not measure demand specifically, and only implied it from the road layout. Due to the seemingly high motivation of drivers to use a mobile phone while driving, this study explores fluctuations in driver workload and performance in a dynamic, simulated environment whereby the surrounding traffic interacted naturalistically with the participant. Might they underestimate their own workload level in dual-task conditions and thus not choose to delay their response to answering a mobile phone call in high workload conditions?

2 Method

The first aim of the study was to quantify the influence of the varying types of lane changes performed by a neighbouring vehicle on driver workload using subjective workload ratings. Secondly, we explored whether drivers would modify or regulate their behaviour to reduce task demand by delaying engagement in a secondary task.

2.1 Apparatus

The experiment was carried out using a high-fidelity simulator with an eight degrees of freedom motion base at the University of Leeds. Participants drove in a 2005 Jaguar S-type vehicle housed within a dome, with the projection system providing a total horizontal field of view of 250° and vertical field of view of 45°. LCD panels are built into the Jaguar's wing mirrors to provide the two additional rear views to allow participants to experience the surrounding traffic to the left and right of the vehicle. The vehicle has all of its basic controls and dashboard instrumentation fully operational (see Figure 1).

Vocal responses to the secondary task were collected manually via a voice recorder (Sony ICD-200X Digital Voice Recorded attached to a Griffin Lapel Microphone). Data were then processed using the Praat audio playback program with sound spectral analysis capability allowing the identification of the sound stimulus and speech response and thus the vocal reaction time measured to +1/-1 millisecond accuracy.

Figure 1 University of Leeds Driving Simulator

2.2 Experimental Design

A standard three-lane motorway (speed limit of 112 km/h) was simulated with occasions of adjacent vehicles (either from the slow or the fast lane) pulling in front of the participants.

Participants were instructed to drive in the middle lane; vehicles in the slow lane were programmed to maintain 60mph (96km/h) and fast lane vehicles travelled at 70mph (112km/h). The lane changes performed by the neighbouring vehicles were manipulated by Lane Change Proximity (5, 10, 15, 20, 25 or 30 metres in front of the participant), Lane Origin of the vehicle (Slow or Fast Lane) and Indicator Use (On or Off). When indicators were used, they were activated approximately 1.9s before crossing the lane divider. To ensure that the indicator was visible, the respective vehicle was always ahead of the participant vehicle before starting the lane change manoeuvre. The adjacent vehicle was programmed to pull in at a certain distance measured as the gap (LC_p, in metres) between the participant vehicle and the cutting-in vehicle as shown in Figure 2.

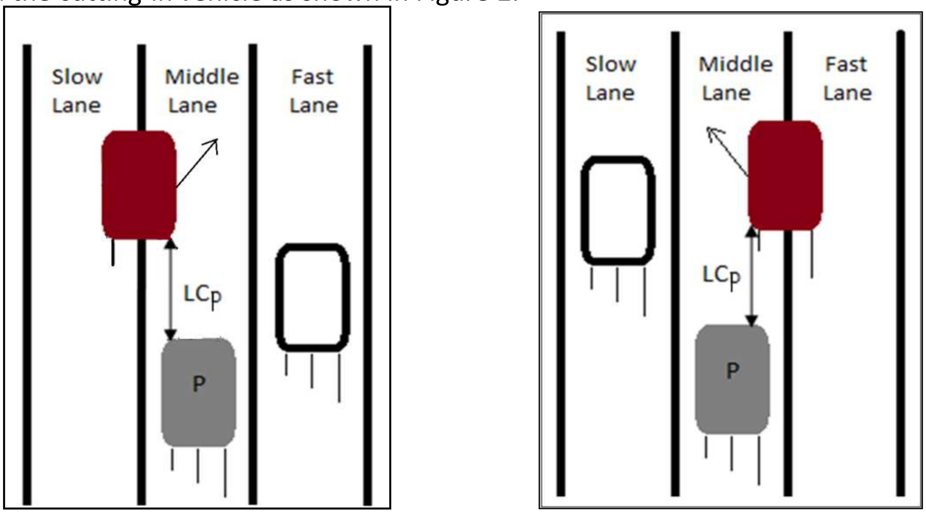

Figure 2: Lane changes showing vehicle overtaking either from slow lane (left) or from fast lane (right), LC_p = Lane Change Proximity, P= participant vehicle

Participants were required to complete three drives each lasting thirty minutes. The first two drives each consisted of twenty-four lane change events and the order of the events were counterbalanced. During these drives, the participant simply had to rate their workload. During the third drive each participant experienced six single-task scenarios involving driving only (with lane changes) and eighteen dual-task scenarios (of which six involved no lane changes and twelve had lane changes occurring at proximities between 5m and 30 m and originating either from the slow or fast lane). An average of 50 seconds (ranging from 30 seconds to 70 seconds) elapsed between each lane change event to ensure that the timing of lane changes were less predictable and more realistic to participants.

2.3 Workload rating task

To evaluate the influence of the surrounding traffic behaviour on driver's momentary subjective workload, a rating task was administered in the first two drives. Participants were prompted with an audible beep every seven seconds, to provide a rating (1-10), to indicate their overall workload. Participants were encouraged to rate their workload by considering the difficulty of the driving task based on the events which they had recently experienced or any events that had occurred since the last rating. This method and rating scale (explained as representing low (1-3), medium (5-6) and high (8-10)) was used by Teh et al. (2014), and baseline ratings were collected at the start of the drive before the first lane change event and at the end of the drive.

2.4 Secondary task

To assess drivers' prioritisation in dual-tasking, participants were presented with a numerical operations task as a surrogate for a phone conversation (a two choice, self-paced response task). This task has been used in many previous studies (McKnight and McKnight, 1993; Shinar et al., 2005) and has been shown to be sufficiently taxing to impact on driving performance. In this study, as in other research (Treffner and Barrett, 2004), the decision to use mathematical problems as materials was motivated by the need for an engaging task that offers a degree of experimental control as well as cognitive effort.

A 'ding-dong' sound was played to indicate an incoming phone call at certain points during the drive and the participants could then respond to these "phone calls" at their own leisure as they would in real life. As soon as participants responded by pressing a button on the steering wheel, five numbers were presented via the audio system, followed by a sum or product question (according to Card et al., 1986, the human auditory storage capacity is five characters). For example,

9, 5, 3, 2, 1 *What is the sum of the first and the fifth number?*

8, 4, 2, 0, 1 *What is the product of the second and fourth number?*

The time taken to answer the call (acceptance time), the time taken in responding verbally with an answer to the arithmetic question (response time) and the questions answered incorrectly (Percentage Errors) were recorded. To motivate secondary task activity, participants were informed that their performance on the secondary task would be monitored and rewarded based on how many questions they answered correctly. No instructions were given regarding expected rapidity of response.

2.5 Participants

Twenty-four participants successfully completed the study ranging between 24 to 45 years old (mean age = 32.2 years, SD age = 6.05 years: 14 males, 10 females). As participants were required to respond to a surrogate mobile phone task, only those who use hands-free phones while driving were recruited in this study. Other general criteria include requiring participants to possess a valid UK driving license and to have been driving regularly for the past five years with minimum annual mileage of 16,000 km. Participants were required to attend the driving simulator for one testing session and were awarded payment of £20 for their participation.

2.6 Procedure

Upon arrival at the driving simulator, participants were briefed and informed consent obtained. They then drove in the simulator four times, one practice run (approximately ten minutes) and three experimental runs. During the practice drive, participants were encouraged to ask questions if they were unsure of any aspect of the driving. Participants then performed three drives, with the first two drives aiming to evaluate workload responses to the lane change events. Prior to the start of the third drive, participants were briefed on the secondary task and shown the location of the response button to indicate they were ready to accept the incoming "phone call". Participants exited the simulator vehicle between the drives, and after the experiment were fully debriefed and paid.

2.7 Measures

Subjective measures of workload were collected along with secondary task and driving performance.

2.7.1 Subjective Workload

From the continuous workload ratings provided by the participants, two measures were derived. *Relative Workload* was defined as the difference between pre-lane change workload rating and that reported during the lane change. The higher the value, the more additional workload was perceived as a direct result of encountering a lane change. Following the lane change, a *Workload Recovery Period* was calculated. This was defined as the time taken to report a constant workload (i.e. the level of workload rating did not change across three consecutive ratings) or baseline workload (i.e. the level of workload measured at the start of the drive). We hypothesised that Relative Workload and Workload Recovery would vary with the characteristics of the lane changes (i.e. Lane Change Proximity, Lane Origin and Indicator Use).

2.7.2 Secondary task performance

The task a*cceptance time* (seconds) was defined as the time elapsed between task onset (i.e. the 'ding-dong' prompt of secondary task) and the first press on the steering wheel button which indicated participants' readiness to engage in the secondary task. *Response time,* also measured in seconds, was defined as the time taken to respond to the arithmetic question measured between the end of the voice message and the first correct answer provided by the participant. Additionally, the accuracy of each of the responses was recorded (i.e. correct or incorrect) for the computation of *percentage error* (%).

2.7.3 Driving Performance

To supplement the measure of workload recovery as outlined in 2.7.1, driver speed was used as a further indicator. Many studies have reported speed reductions under dual tasking conditions (e.g. Haigney et al., 2000) and is related to be a compensatory behaviour in order to reduce overall task demand. In this study we used speed measured directly after a lane change as an objective measure of task demand, particularly as there may be dissociations between perceived and actual demand (Yeh and Wickens, 1988). As participants were instructed to drive at 65mph (104km/h), they were incentivised to maintain a steady speed and this provided them with a reason to increase their speed to this level each time they encountered a lane change event that required them to brake. Using a method reported by Strayer et al., (2006), a measure of half-time recovery was calculated from the speed data. This was defined as the time taken for drivers to recover 50% of the speed that was lost following a lane change event. For example, if the participant was travelling at 30m/sec before braking and decelerated to 22m/sec after braking, then half time recovery was calculated as the time taken to return to 26m/sec.

3 Results

The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively and tested for sphericity. Greenhouse Geisser correction was applied where necessary.

3.1 Subjective Workload

3.1.1 Relative Workload

This measure provides an indication of the additional workload that a driver perceives as a result of a neighbouring vehicle performing a lane change in proximity. A three-way repeated measures ANCOVA analysis was performed with Lane Change Proximity (6 levels), Lane Origin (2 levels) and Indicator Use (2 levels) being the within-subject factors. Baseline workload (workload at the start of the drive) was included as the covariate. Significant main effects of Lane Change Proximity, ($F(3.18, 66.70)=71.917$, $p<0.001$, $\eta^2=0.794$) and Lane Origin, ($F(1,21)=93.513$, $p<0.001$, $\eta^2=0.873$) on relative workload were found. Workload increased as Lane Change Proximity decreased and was higher when drivers experienced a merging vehicle originating from the slow lane compared to the fast lane (Figure 3). Pairwise comparisons indicated that the effect of Lane Change Proximity on Relative Workload was not significant beyond a pulling-in distance of 20m. A significant interaction between Lane Change Proximity and Lane Origin, ($F(3.37,70.81)=3.578$, $p=0.015$, $\eta^2=0.146$) was found, indicating that when Lane Change Proximity of the merging vehicle was less than 20m, the effect was greater when it originated from the slow lane as compared to fast lane. There were no effects of Indicator Use on relative workload.

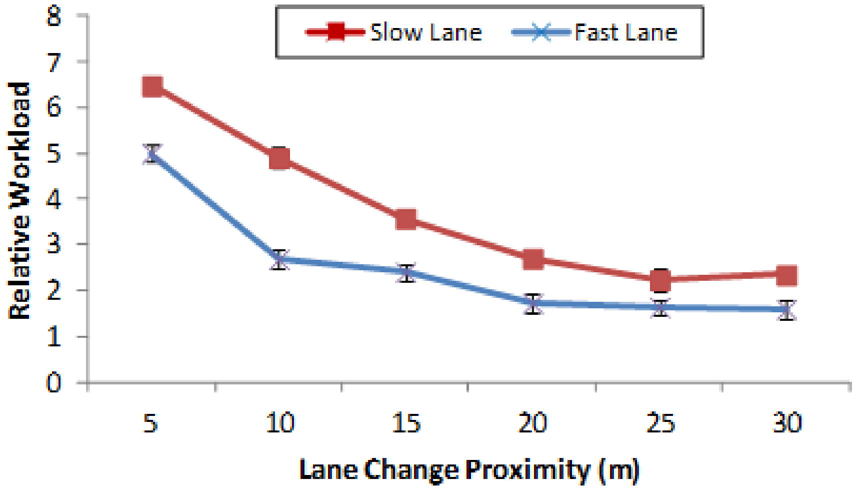

Figure 3: Relative Workload (with standard errors)

3.1.2 Workload Recovery Period

Using the same within-subject factors as for relative workload, a three-way repeated measures ANOVA analysis was performed on the workload recovery data. Significant main effects of Lane Change Proximity, ($F(2.59,59.51)=69.245$, $p<0.001$, $\eta^2=0.751$) and Lane Origin, ($F(1,23)=88.452$, $p<0.001$, $\eta^2=0.794$) were found, whilst Indicator Use was not significant. Pairwise comparisons showed that the workload recovery period increased with decreasing Lane Change Proximity up to 20 m. Drivers recovered significantly more slowly after experiencing a lane change from the slow lane compared to the fast lane (Figure 4). The absence of an interaction effect indicated that Lane Origin influenced the workload recovery period for all Lane Change Proximities. Since the minimum average Workload Recovery Period obtained in this study is 11.188s, the minimum amount of time that a driver requires to recover from this traffic event can thus be estimated to be approximately 12 seconds.

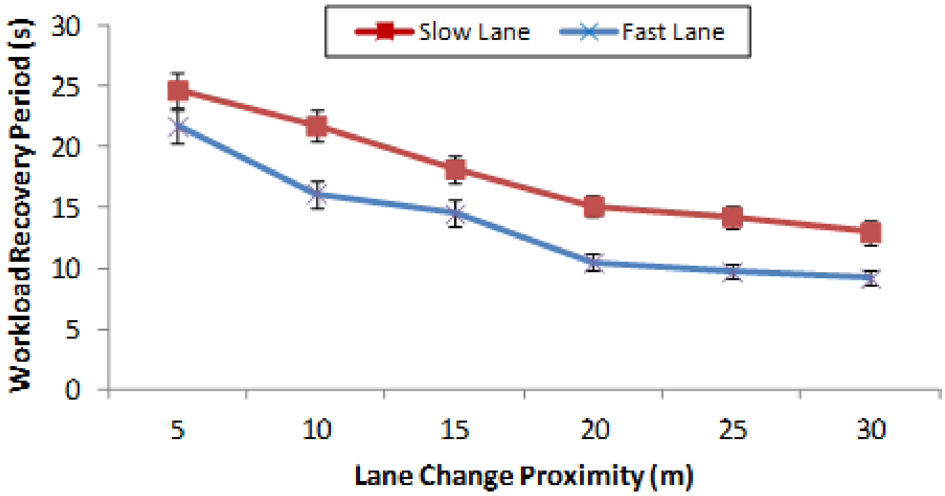

Figure 4: Workload Recovery Period (with standard errors)

3.2 Secondary Task Performance

The data obtained from the third drive allowed the investigation of the effect of Lane Change Proximity and Lane Origin on secondary task performance via acceptance time, response time and percentage error.

3.2.1 Task acceptance time

Acceptance time data were not normally distributed. Reciprocal-transformation was effective in reducing problems relating to skew and kurtosis and therefore, parametric testing was performed on the transformed data set. An ANCOVA with two within-subject factors, Lane Change Proximity and Lane Origin, was performed. Acceptance time where no lane change occurred served as the covariate.

The analyses showed statistically significant main effects of Lane Change Proximity, ($F(5,110)=16.690$, $p<0.001$, $\eta^2=0.326$) and Lane Origin, ($F(1,22)=19.704$, $p<0.001$, $\eta^2=0.447$) on task acceptance time. Drivers initiated the task more slowly when the lane change performed by the neighbouring vehicle occurred at a closer proximity, with pairwise comparisons indicating this effect dissipated beyond 15m (Figure 5). Acceptance time was faster where the vehicle originated from the fast lane and, with the interaction approaching significance ($p=0.051$), visual inspection of Figure 5 suggests that the Lane Origin effect is negligible beyond 15m.

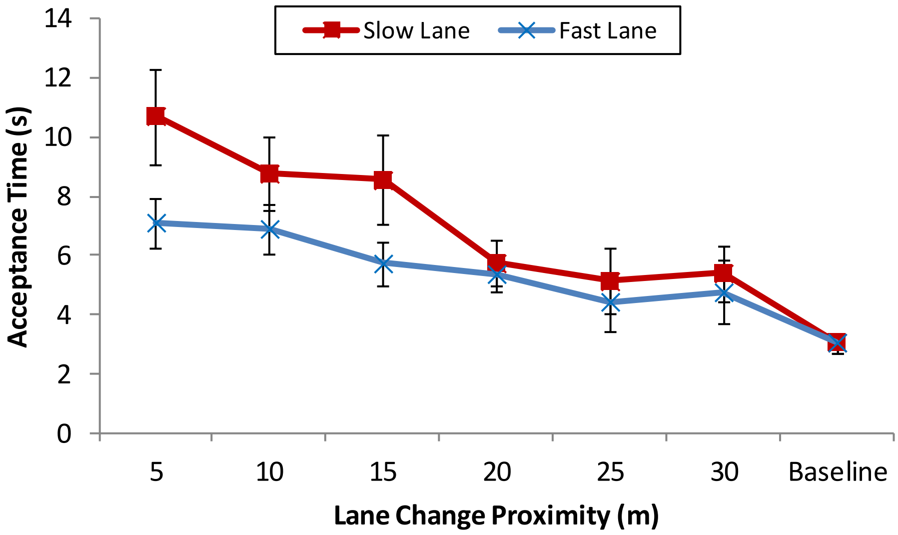

Figure 5: Effect of Lane Origin on Acceptance Time (with standard errors)

3.2.2 Response time and performance accuracy

Upon acceptance of the secondary task, the time taken to respond to each arithmetic question was calculated. Using ANCOVA with Lane Change Proximity and Lane Origin as within-subject variables and response time in baseline events as the covariate, no significant main effects of either variable were found.

Incorrect responses to the secondary task were relatively rare. Each participant performed six trials whilst driving in a stable environment (i.e. baseline) and twelve trials which occurred during lane change events. Of the 24 participants, only one participant made more than three errors (out of a maximum of 18). Despite the overall high level of accuracy, it is clear that, where errors did occur, they were largely confined to conditions involving close proximities (Figure 6).

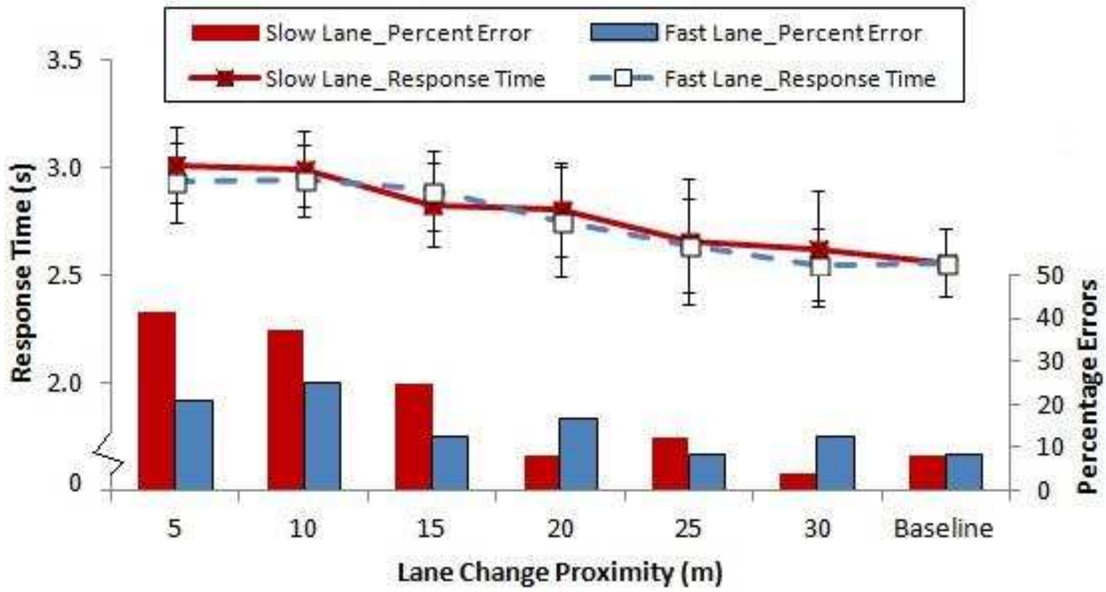

Figure 6: Secondary task response times (with standard errors) and error rates

Since the percentage error data was not normally distributed and transformations were ineffective at normalisation, non-parametric testing was used. Wilcoxon Signed Rank tests confirmed differences between baseline and the near Lane Change Proximity scenario (5m), T=0, $p<0.05$.

3.3 Driving Performance

The difference in speed 7s before and after a lane change was computed. A two-way repeated ANOVA was conducted using Lane Change Proximity and Lane Origin (two levels) as factors. There were significant main effects of Lane Change Proximity ($F(3.14, 59.98)=36.124$, $p<0.001$, $\eta_2=0.440$) and Lane Origin ($F(1,23)=25.939$, $p<0.001$, $\eta_2=0.775$) on mean speed reduction. The reduction was significantly larger up to 20m proximity and when the vehicle approached from the slow lane. A significant interaction of Lane Change Proximity x Lane Origin, $F(2.307,68.83)=6.886$, $p=0.011$, $\eta_2=0.087$) indicates the effect of Lane Origin is not present beyond 20m. Figure 7 shows the speed profiles which were created by extracting 12s-epochs (from the onset of the merging vehicle moving laterally 2s before crossing the lane divider and staying in front of the participant vehicle for 10s after pulling in).

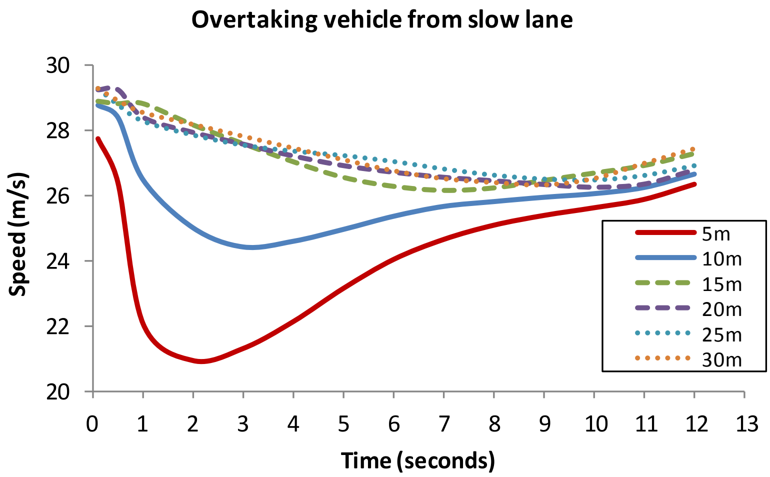

Figure 7a: Speed profile by Lane Change Proximity when overtaking vehicle approaching from the slow lane

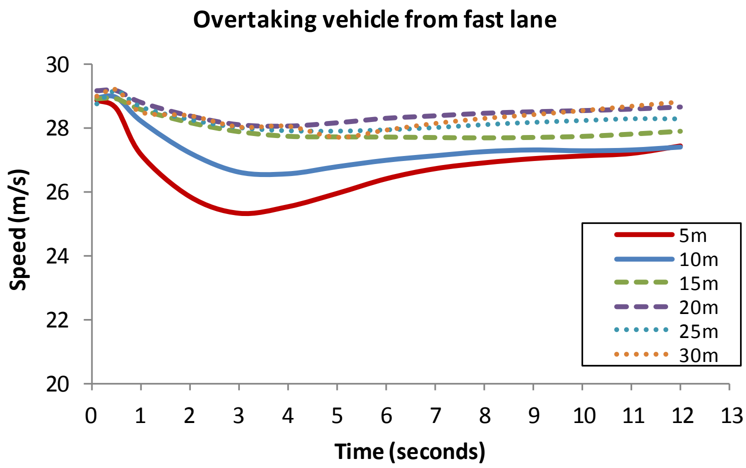

Figure 7b: Speed profile by Lane Change Proximity when overtaking vehicle approaching from the fast lane

Half recovery time was calculated for each lane change where braking was observed. Since not all participants braked in all events (especially in distal proximities), the half recovery times were regrouped into three categories: close proximity (5m and 10m), medium proximity (15m and 20m) and low proximity (25m and 30m). Using a 3x2 repeated measure ANOVA (three levels of Traffic Proximity and two levels of Lane Origin) a significant main effect of Traffic Proximity on half recovery time was observed, ($F(2,46)=8.938$, $p=0.007$, $\eta^2=0.280$). In closer traffic proximity situations, participants reacted more quickly to recover the speed that was lost during braking, possibly due to greater urgency of the traffic situations thus increasing participants' level of arousal during lane change. No significant effect of Lane Origin on half recovery time was however found.

Plotting both the objective and subjective data together (Figure 8), even at relatively distal interactions with traffic (30m) and where time-to-collision was infinite, drivers in general required a minimum time duration of 12s (subjective) or 15s (objective) to recover.

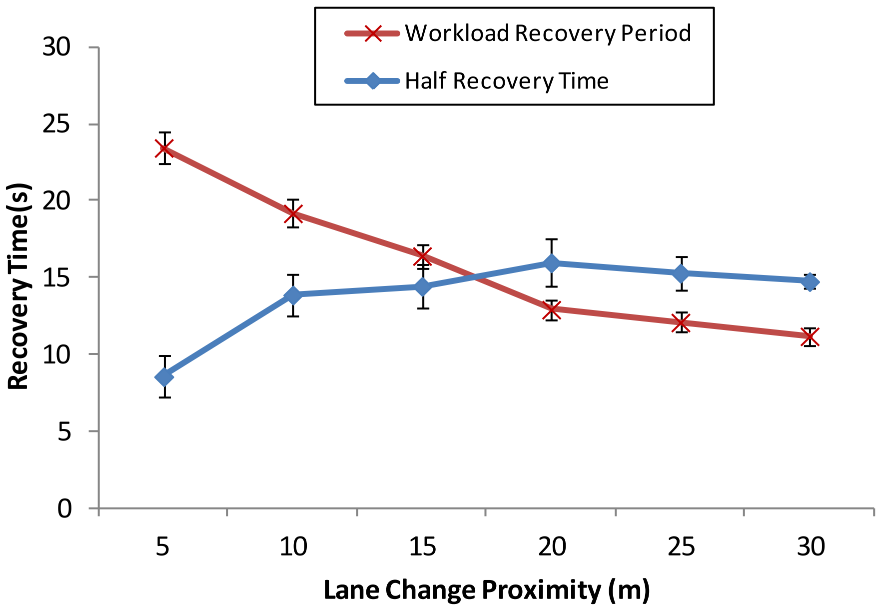

Figure 8: Comparison of mean workload recovery time (with standard errors) measured subjectively and objectively

4 Discussion

This study aimed to explore the influence of the surrounding traffic on driver workload in a simulated environment, with a focus on examining the characteristics of a lane-change performed by an adjacent vehicle. Subjective workload measures were used to capture the drivers' perception of the driving demand of various manipulated traffic events. Participants in this study were required to actively assess and differentiate their own momentary workloads via verbal ratings collected on a frequent basis. This study also investigated whether drivers would employ any delays in initiating a secondary task depending on external traffic demands.

Using subjective workload measures, we were able to demonstrate that drivers were sensitive to the behaviour of the surrounding traffic; workload ratings varied depending on both the proximity of a merging vehicle and its lane origin. The closer the vehicle (within 20m or less) the higher the perceived workload; this was exacerbated if the vehicle merged from the left, which is generally unexpected and discouraged in the United Kingdom. Whether or not the merging vehicle used their indicator to signal their intention to move across, had no effect on workload ratings. Beyond 20m in front of the driver, the effect of the merging vehicle was negligible; converting this distance into an approximate time headway, based on the participant's speed being 104km/h, we obtain a value of 1 second. This supports a number of studies which have shown that normative following behaviour is close to this value (Chen, 1996; Taieb-Maimon and Shinar, 2001; Van Winsum and Heino, 1996). So, as long as merging vehicles remain outside this comfort zone, drivers do not experience increases in workload.

From the perspective of driver awareness, this finding is encouraging as it indicates the ability of drivers to evaluate constantly their own level of workload, and adds weight to those conclusions drawn by Kidd et al. (2016): they found that drivers appear to engage in secondary tasks when they perceive the level of roadway demand to be low. Using observational surveys they reported that the likelihood of drivers engaging in secondary tasks was highest when stopped at red lights and lowest at roundabouts. However, their study was carried out in an urban area, where intersections (and one assumes roadside parking) allow drivers to experience or actively seek out very low levels of driving demand to then engage in additional non-driving activities. The study reported here, however, was carried out on a simulated motorway, where there was no opportunity for drivers to stop and the instruction was to maintain a speed as close to 65mph (104 km/h) as possible. Thus the pressure of driving demand, in terms of maintaining their lane position and speed, did not relent and drivers were forced to self-manage their other tasks in order to maintain their ideal level of workload, or feelings of risk (Fuller, 2008).

This study hypothesised that workload may also not be momentary and the "effects" of a high demand situation may persist even when the "threat" has passed. Thus workload was measured continuously allowing the calculation of a workload recovery period. The results suggest that workload recovery was slower in the high demand scenarios. It was not simply the case that workload ratings peaked as the merge occurred and then dropped to baseline straight after. We observed persisting workload increases for up to 24 seconds afterwards, for the most demanding events. This finding has both methodological and practical implications. First, when investigating mental workload in any domain, single snapshots are best avoided – and the time domain over which measurements are sampled should be long enough to capture these "hangover" effects. Continuous monitoring of workload via physiological measures is, of course, one way of ensuring the effects are captured; but when this is practically or financially challenging, as in the case of naturalistic driving studies, then care should be taken to ensure that the sampling window is sufficient or indeed continuous (as argued by Carsten et al., 2013). Some on-road studies use a combination of event driven-data coupled with continuous sampling (e.g. University of Michigan Transportation Research Institute and General Motors, 2005). However their pre-defined events triggered video to be stored for a period of four seconds before and four seconds after the event. We would argue this window is not sufficient given our results.

The increases in workload we observed in the close proximity situations were likely due to the rapid changes in speed (active braking) that participants performed. In our paradigm it was not the case that increased workload instigated decreases in speed as has been found in other dual-tasking studies (e.g. Haigney et al., 2000); clearly in our study the direction of the effect was the opposite. Having to reduce speed and then accelerate to maintain the instructed speed was reflected in the workload scores. Drivers were no longer engaging in speed maintenance, but speed regulation. And the literature on the relationship between speed variance and crash likelihood has been widely reported (e.g. Garber and Gadiraju, 1989).

By being able to measure perceived workload following an event and then quantifying the recovery zone, we were then able to discover if drivers encroached into the zone in order to respond to a secondary task. Once presented with the opportunity to engage in the secondary task, drivers, in general, applied a time delay in responding in the most demanding traffic conditions (lane changes within close proximity). While the delay duration (i.e. acceptance time) increased with increasing driving demand, it only ranged between 6s and 10s, and was shorter than the workload recovery period (which ranged between 12s and 24s). Visual inspection of Figure 9 shows that percentage errors is roughly equated to the difference between Workload Recovery Period and Total Response Time. Total Response Time is defined as the sum of Acceptance Time and Response Time in completing the secondary task. The finding that secondary task errors (i.e. percentage error) were higher in lower Lane Change Proximity conditions, particularly in demanding traffic situations such as Lane Change Proximity 5m and 10m, suggests that the delay employed was not adequate to mitigate against the effects increased workload.

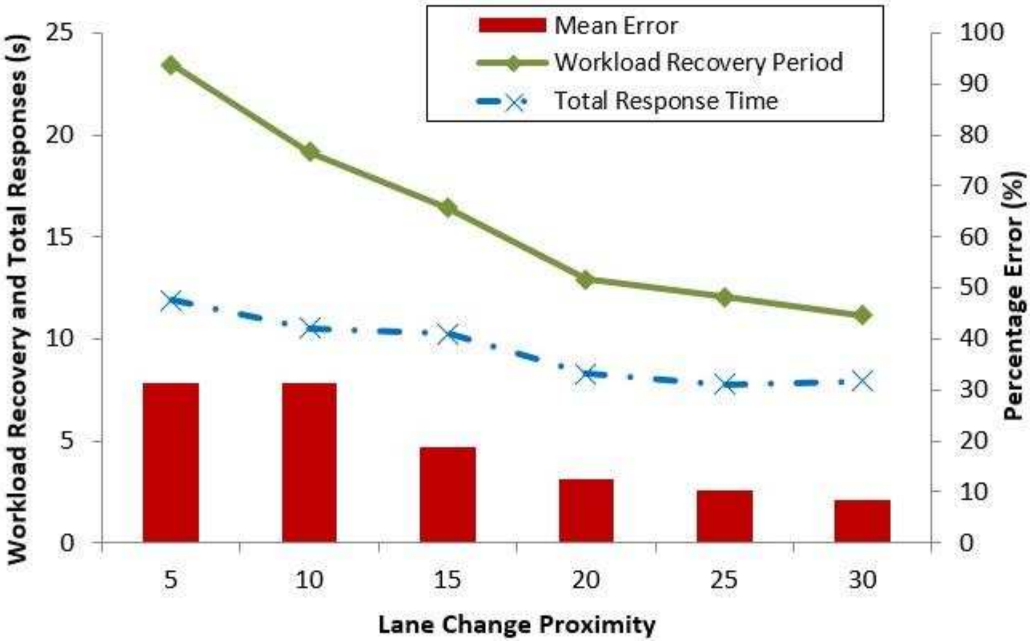

Figure 9: Workload Recovery Period, secondary task Total Response Time and Percentage Error

The implications of this result are pertinent particularly with respect to the timing of presentation of in-vehicle information. Today, as drivers are exposed to an increasing amount of information provided by in-vehicle systems such as driver assistance and navigation systems, managing the timing of (non-critical) information is a challenge. Workload management functions have been developed whereby based on the interactions of the in-vehicle functions with the driver, information is prioritised or put on hold in demanding driving situations if the information are deemed non-critical (Engström et al., 2004, Broström et al., 2006). Incorporating the workload imposed on drivers by external traffic events could be the next step in increasing the functionality and reliability of workload managers.

However, this brings us to one of the limitations of the study – only one specific behaviour of the other traffic was manipulated and there are doubtless others which affect driver workload, such as lane deviations, sudden braking etc. We selected a behaviour that could be quantified and manipulated easily and in doing so allowed us to vary task demand. A further limitation is that both the simulator and the secondary task may suffer from a lack of ecological validity, although it is hard to imagine how such an on-road study could be ethically approved or even orchestrated. With regards the secondary task, it may be less realistic (possibly also less urgent) than those drivers typically encounter. However, this only makes our results more compelling, whereby if the drivers were willing to engage in a laboratory task with very little incentive, how quickly might they do so in the real world? How far into the workload recovery zone might they encroach? Finally, the participant sample was relatively young (less than 45 years old). Neither very young (or novice) nor older drivers were included. Each might be motivated more or less to respond to an incoming text or phone call (Jamson, 2013 reported that compared to older drivers, 21-24 year olds were almost 20 times more likely to admit to texting while driving). Also, there may be age-dependent effects of workload and the ability to dual-task (Watson and Strayer, 2010 proposed the idea of "supertaskers", whereby some individuals have extraordinary ability to multitask while driving).

Despite these limitations, this study offers the following contributions to the field of driver workload:

i. Driver workload fluctuates depending on the behaviour of surrounding vehicles, specifically when merging into the same lane. The temporal persistence of the increased workload also varies, with maximum values of 24 seconds. Both proximity and lane origin of a merging vehicle are important factors.
ii. Drivers can report these fluctuations in workload via a simple subjective scale. Whilst the sensitivity of subjective workload to fluctuations in demand has already been reported in the literature (e.g. Matthews et al. 2015), this study, by employing a continuous measure of subjective workload could track the changes in the temporal domain and offers additional insight compared to single measures captured post-experimentally (e.g. NASA-TLX, Byers et al. 1989).
iii. Whilst drivers delay their response to a (driver-paced) secondary task in times of increased workload, their responses occurred inside the workload recovery period. This impacted on their secondary task performance.
iv. In terms of a workload manager, using radar or sensors readily available in a vehicle, information pertaining to the movement of neighbouring traffic can be monitored and included in the 'watch-list'. This study suggests that a delay of 12 seconds or more, following a close incursion, may be advantageous to drivers. Moreover, the use of workload manager may have merit not only for the benefit of younger drivers but also for older drivers, who may otherwise be overwhelmed by the workload arising from both driving task and secondary task. Further studies of understanding how and when different age groups of drivers practice self-regulation in these safety-critical situations to ensure safe driving may be advantageous.

To ensure that the findings can be generalised to the real-world driving, this study focuses on a distracting task that is relevant to drivers. The use of surrogate mobile phone task as the distracting task to examine driver's task prioritisation during high workload conditions in this study has shown that, drivers do not tend to be well-calibrated to their own level of performance. Drivers tend to be overly optimistic about their ability to perform in-vehicle activities (Horrey, Lesch, and Gabaret, 2008; Wogalter and Mayhorn, 2005) and errors were still prominent despite driver's implementation of self-regulation. In regards to hands-free mobile phone usage legislation, it may be possible for government to consider implementing assistance systems such as workload managers to help drivers cope with increasing amount of information while driving.

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