Do drivers prioritise primary driving tasks over secondary tasks within driving simulators? A comparison of simulators of varying fidelity

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Abstract

There is a fundamental lack of understanding concerning the relationship between the fidelity of driving simulators (extent to which simulators replicate reality) and validity (extent to which drivers behave as they would in equivalent real-world situations). For distraction research, knowledge on how drivers prioritise primary driving tasks over secondary tasks can be a potential indicator of simulator validity. Theoretical propositions, consequently established in on-road research, show that higher primary task demands result in increases in time pressure and forward spatial-scene uncertainty, prompting drivers to return their vision to the road ahead in a predictable fashion. This paper addresses whether drivers within simulators of varying fidelities exhibit the attention behaviour and time-sharing strategies predicted by theoretical and empirical research. Twenty-four drivers drove in two (low and medium-fidelity) simulators following a simple rural-road scenario comprising straight and curved-road driving, whilst performing a series of visual search tasks using an in-vehicle display. Results showed that drivers exhibited the predicted visual attention behaviours in both simulators. Nevertheless, the low-fidelity simulator was associated with reduced lane keeping performance, due primarily to physical, rather than psychological differences in the driving experience. It is concluded that driving simulators of varying fidelity can successfully be employed in distraction research.

Introduction

Driving simulators are among the range of essential tools used for distraction research. With driving simulators, researchers and drivers benefit from an intrinsically safe driving and research environment. Potentially dangerous situations can be investigated without endangering the driver or other road users (Lee et al., 2003). Simulators can be easily configured to investigate numerous human factors, engineering and design issues, for example considering novel roadway infrastructure, road marking schemes, methods of signage etc. (Törnros, 1998, Dutta et al., 2004). Nonetheless, various concerns collectively impact on how driving simulators are perceived and used, for instance:

- Simulator fidelity - the extent to which simulation imitates reality;
- Validity – the extent to which a simulator actually measures what it is aiming to measure;
- The experience of participants within a simulation environment, including issues of motivation, engagement, etc.

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The issue of validity is unquestionably the most problematic. Past investigations have reported on the time-consuming, expensive participant recruitment process, practical development issues and ethical concerns of conducting comparable simulator-road trial to assess validity (Kaptein et al., 1996, Hoskins and El-Gindy, 2006). Validity is recognised as a complex function of a large number of variables, e.g. motivation, driver's response(s) to specific driving task and conditions, fidelity etc. but only subsets of these are typically investigated for simulated driving tasks. The low number of variables in prior validity studies creates difficulties when generalising results to real-word situations (Peters and Peters, 2002). Regarding the overall driving experience, questions still remains on how driving simulators absorb drivers, such as drivers' physical, behavioural, physiological and psychological experience in the simulator and the effect of these on driving behaviour and performance (Insko, 2003).

Fidelity is also considered an issue for several reasons. Questions such as whether the dynamics of a simulator should match that of the vehicle it is replicating remains debatable. Modern simulators vary on a range of physical fidelity dimensions (i.e. does it look, feel, sound like a car one would expect in the real world) and psychological fidelity characteristics (i.e. does the simulator represent the driving task in the same fashion as on-road driving). In terms of physical characteristics, simulators are roughly grouped into low, mid and high fidelity levels. Institutions implement different levels for various reasons e.g. cost and space for low-levels, however, there is a lack of awareness of the effects of different levels of simulator fidelity on driver behaviour and experience. Some research suggests that the capability and functionalities of a simulator can have significant impact on drivers' behaviour and performance. For instance, Bach et al. (2008) report that the lack of sensory and spatial visual feedback in their simulator generated difficulties in drivers' ability to control the vehicle and created higher reluctance to interact with a secondary task in a study. Furthermore, it often assumed that the higher the fidelity, the greater the reliability of observed behaviours, the greater the "experience" and the greater the validity of a simulator. Although this assumption may hold for certain kind of investigations (e.g. early development of a vehicle, road geometric evaluation), it is vital for researchers to investigate driver's interaction and performance when simulators are used for research purposes. Understanding the associations between a driver's perception of a simulation, their technological experience and psychological state of mind (Coelho et al., 2006) could inform the research community on the specific type of simulator to use to address certain research questions. For distraction research, investigating the consistency of a driver's visual and physical behaviours in different driving simulators and how that compares with expected behaviour in the real roads would be of importance. Such knowledge would enable researchers to gain a better understanding of drivers' interactions in simulations and distraction studies as a whole.

Knowledge on driver behaviour and concurrent primary driving and secondary task performance is a potential indicator of simulator validity. It has been established that driving while performing a secondary task (e.g. a visual search task) creates a situation where the drivers' visual and attentional resources are time-shared between both tasks (Wickens et al., 2004). Theoretical propositions on driver visual sampling strategy by Senders et al. (1967) and Zwahlen et al. (1988) postulate that when drivers look away from the road scene, for example to perform an in-vehicle task, the amount of known road and traffic information gradually decreases because input ceases. A minimum amount of road information has to be timely maintained in memory to ensure adequate driving performance. When the threshold is reached, drivers must return attention to the road scene to update the decreasing information. This model of driver visual attention and time sharing has been tested in various driving environments.

In a series of on-road studies, Wierwille (1993) established that higher demands on driving results in increases in time pressure and forward spatial scene uncertainty, prompting drivers undertaking in-vehicle secondary tasks to return their vision to the road ahead. Drivers spend a limited amount of time (typically no longer than 1.6sec on each glance) chunking information from in-vehicle targets until information is fully acquired. Significant empirical evidence provided by Lansdown (1997) also supports this visual sampling behaviour where drivers make adjustments in secondary task interactions. The effects of visual demand imposed by the secondary task on driving performance have also been extensively studied. Green (2002) explained that a driver's visual attention diverted onto an in-vehicle task results in periods where the road scene isn't monitored. Well-known performance degradations subsequently occur, e.g. variation in lateral position, lane keeping errors and heading errors (Greenberg et al., 2003, Engström et al., 2005). Other studies have also found an effect of visual load of in-vehicle tasks on longitudinal vehicle control, i.e. reduction in speed and increase in speed variability (Horberry et al., 2006).

A preliminary study by Donkor et al. (2011) investigated the comparability of drivers glance behaviours in a medium-fidelity simulator with typical real-world behaviours (based on the above empirical and theoretical foundations from the literature) as an alternative approach to simulator validity. It also examined the drivers' perception of "presence" in the simulator and how that is reflected in the driving behaviour. Using a simple method i.e. changing primary task demand (driving from straight to curve road) with a concurrent secondary task, drivers' glance behaviours (glance duration, glance frequency) in the simulator were compared with well-established on-road behaviours. The results supported the hypotheses that with increasing demand in the primary driving task, drivers adapt to primary task demand changes by adjusting glance behaviour and driving performance. Glance behaviours were comparable with established on-road research, confirming the relative validity of drivers' visual scanning behaviours commonly employed in distraction research. Drivers exhibited inherent differences in behavioural adaptations and time-sharing strategies. Furthermore, drivers reported higher level of spatial presence, engagement and degree of realism, but such high ratings were weakly associated with drivers' behaviours and performance.

This paper considers drivers' visual behaviour and time-sharing strategies predicted by theoretical and empirical research in two simulators of varying fidelity characteristics. We investigate the importance that drivers place on the primary driving task over the secondary task – a critical factor when considering the validity of driver glance behaviour and driving performance for distraction research. Specifically, we hypothesize that with increasing primary driving task demand, drivers will make an increased number of glances towards the secondary task display; reduce the duration of individual glances towards the display, whilst the overall secondary task completion time increases. These are all behaviours typically seen in situations with increased primary task demand. Subsequently, such adaptations in visual attention allocation will affect a driver's ability to maintain longitudinal performance (reduction in speed) and lateral positioning (increase in lane excursions). Of significance to this paper is whether these effects would be different in medium and low-fidelity simulators.

Method

Participants

Twenty four drivers volunteered to take part in this study. The average age was 29.9 years (SD = 8.48, range 22-52). All drivers held a valid full UK driving licence (mean driving experience = 10 years, SD = 7.24), drove a minimum of 8000 miles per year and on average drove 5 days per week on UK roads. All drivers were in good health, with normal hearing ability and normal/corrected-to-normal vision.

Materials and Apparatus

Driving Simulators

The study took place in two driving simulators (a low-fidelity and medium-fidelity simulator) - see Figure 1 and Table 1. The medium fidelity simulator is a fixed-base right-hand drive immersive simulator with original pedals, indicators and steering wheel. Three overhead projectors display driving scenarios from an off-the shelf software system (STISIM Version 2.08.03) with advanced driving control interface. The scenarios are projected onto a cylindrical wrap-around forward screen with rear and side mirror projections provided by an LCD TV and mini LCD display panels. The Low-fidelity simulator is a desktop PC simulator with driving controls provided by the use of Logitech G27 steering wheel and pedals set (accelerator and brake). The desktop configuration uses the STISIM software and has its rear and side mirrors simulated on three monitor display screens. The table shows the objective difference between the two simulators.

Table 1 Objective differences between Low and Medium Fidelity Simulators

Low Fidelity Simulator	**Medium Fidelity Simulator**
Steering and Pedal feel characteristics	
• 10" Steering wheel with force feedback • Mounted stainless steel pedals	• 14" Steering wheel with force feedback • Original suspended pedals high stability and enhanced pedals
Display and Field of view (FOV)	
• Real time scenarios displayed by three overhead HD projectors • Virtual FOV of ~135°	• Real time scenarios display by three 24 inches full HD monitors • Virtual FOV of ~ 270°
Reach and Secondary task location	
• Secondary display positioned within comfortable reach distance of 0.3m to 0.6m (both 5%ile and (95%ile male and female)	• Secondary display located at the centre console and reach distance of 0.3m to 0.6m (both 5%ile and (95%ile male and female)

Figure 1 Low-fidelity simulator (left) and Medium fidelity simulator (right) used in this study

Driving Scenarios

Two short scenarios – Drive 1 and Drive 2 - each comprising a single carriageway rural road (2-lanes), 16000ft long and with traffic on the right-hand side of the road was used in this study. Drive 1 involved a drive on a stretch of straight road followed by a curved road (shown in figure 3) and Drive 2, the vice versa. The scenario also contained mid-section and other monotonous sections to allow drivers a period of uninterrupted driving.

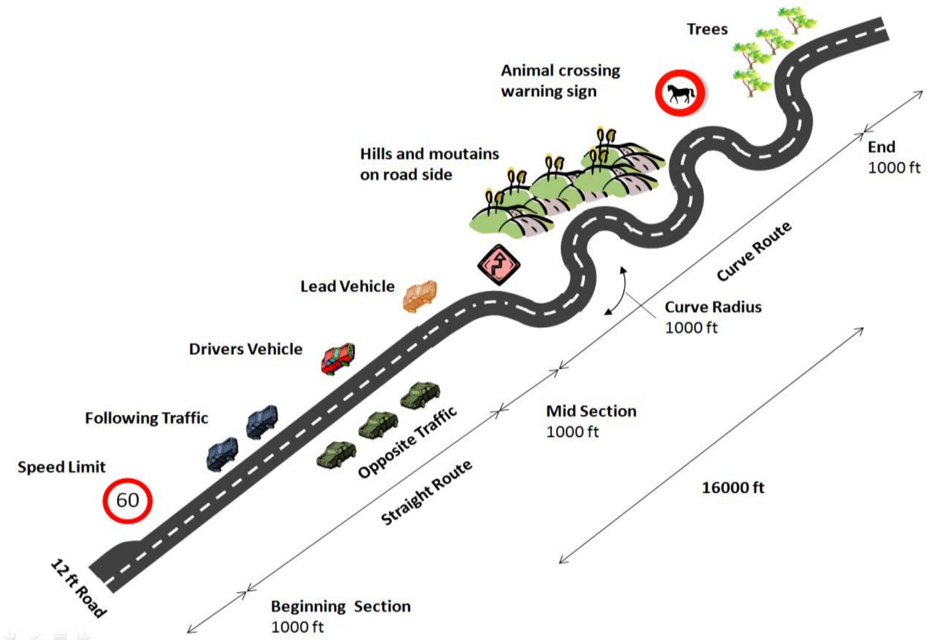

Figure 2 Driving scenario (Drive 1) used in this study

Experimental design

A repeated measures experimental design with two independent variables: the driving environment (Low fidelity and Medium fidelity simulators) and driving task demand (low for straight road and high for curved road) were used in this study. All participants drove using the two driving simulators in a counter-balanced design.

Measures

Driver glance behaviour measures were defined by ISO:15007-1 (2002). The following driving and secondary task performance and driver overall performance measures are reported in this paper. Measures across both straight and curve roads were sampled at 10 Hz throughout.

Visual behaviour and Task Performance

- Mean Glance Frequency: The average number (n) of glances made towards the secondary display
- Mean Glance Duration: The average time (seconds) between the direction of gaze to and from the secondary task display
- Mean Secondary Task Time: The average of the total time from the start of the task (i.e. first glance towards the target) to when the target button is pressed across eight secondary tasks for each road condition.
- Visual Attention Allocation (VAA): The percentage time spent looking at the secondary task display. Visual attention allocation to the secondary task was calculated as the percentage of total eyes off road time (the cumulative time in which a driver looks away from the road scene when completing the secondary tasks) divided by total secondary task time for each road condition for each driver.

Driving performance

- Speed (mph): The longitudinal velocity on both straight and curve sections
- Speed Variability (mph): The standard deviation of the speed across either the straight or the curve section of the road
- Lane deviation (ft.): This referred to the extent to which the driver's vehicle deviated from the intended drive path in a lane. A lane was defined as a single direction lane (12 feet wide) including centre stripes and edges markings (10 feet long, 0.333 feet wide and 10 foot spacing between lines). Lane departure constituted the number of times the lane markings were encroached upon. Specifically, a lane departure was recorded when the tires of the driver's vehicle travelled beyond the outer side of the paved portion of the road edge markings (in the driver's direction) and the driver had not signalled a lane change. Both left and right lane markings on a driver's lane were included in this analysis.
- Lateral variability (ft.): The standard deviation of lateral displacement values of the vehicle from the mean lane position on both straight and curve roads.

Self-reported driving performance

Drivers rated their overall driving performance in each of the two simulators on a 5-point Likert-scale where 1= Not-at-all and 5 = Extremely-well.

Procedure

Drivers completed a consent form and questionnaire concerning their demographics and driving experience. Drivers then undertook a series of practice drives to familiarize themselves with the primary and secondary tasks using both simulators. Practice drives in both simulators included a short stretch of rural road with posted speed limits and some features of the experimental drive (i.e. included straight and curve road sections). They completed the experimental drive only when they felt confident they were able to. Drivers were instructed to concentrate on driving but not to ignore the secondary tasks. Starting from a lay-by lane, the drivers were required to follow a lead vehicle travelling at a speed of 60mph at a perceived safe distance. Drivers were asked to perform a visual search task using the in-vehicle touch screen located within the centre console of the medium-fidelity simulator vehicle and on a modelled cradle in the low-fidelity simulator. On 16 occasions (8 for straight road, 8 for curved road) drivers were presented with a 4x4 array of buttons on the touch screen, alerted by a beep to find and touch the button with the target text “AC”. The AC button was randomly located within the array. All drivers were tested in both simulators, one drive after the other and rated their driving performance during the breaks in between drives. Individual drives included sections without any distracting task. The complete study lasted about 45 minutes.

Results

Videos of driver behaviour and interaction with the secondary task were recorded, played back at 25fps and analysed frame-by-frame using Observer XT 11.0. Performance data were collected using the STISIM data collection functionalities. For each measure, the mean, standard deviation (SD) and 95% confidence interval (95% CI) were computed. All data were analysed using 2x2 Repeated Measures ANOVA with significance level specified at p <0.05.

Glance Frequency and Glance Duration

Analyses of driver glance data (shown in Table 2) revealed a consistent increase in glance frequency towards the in-vehicle display but a decrease in single glance durations as driving task demands increased.

An ANOVA test showed a significant difference in glance frequency across road type F (1, 23) = 88.90, p < 0.001, with a mean increase of 7.79 glances on a curved compared to a straight road. There was no significant main effect of simulator fidelity and no interaction.

Table 2 Mean glance frequency and glance duration by Road Type and Simulator Fidelity

Road Type			Simulator Fidelity Low	Medium	Low	Medium
			Glance Frequency (n)		Glance Duration (sec)	
Straight	Mean(SD)		10.92 (2.48)	9.88 (2.44)	1.40 (0.19)	1.51 (0.27)
	95% CI	Lower	9.92	8.9	1.31	1.4
		Upper	11.91	10.85	1.46	1.6
Curve	Mean(SD)		18.08 (4.56)	18.29 (6.87)	0.66 (0.11)	0.62 (0.09)
	95% CI	Lower	16.26	15.54	0.62	0.59
		Upper	19.91	21.05	0.71	0.66

There was a significant interaction effect of road type and simulator fidelity on glance duration F (1, 23) = 7.09, $p < 0.05$, indicating that the duration of drivers' single glances significantly differed on road type and across driving simulators. Examination of the results suggests that the significant interaction was due to the bigger difference between glance duration for the medium fidelity simulator compared to the low fidelity simulator. A significant effect of road type was also shown F (1, 23) = 629.45, $p < 0.001$. There was no significant main effect of simulator fidelity.

Secondary task time

Secondary task times for each road condition in both simulators were computed for all participants. In situations where participants had less interaction with the secondary tasks, the maximum task time were recorded until the next task was presented.

Table 3 Mean secondary task time by Road Type and Simulator Fidelity

Road Type	Task time (sec)		Simulator Fidelity Low	Medium
Straight	Mean(SD)		4.89 (1.91)	4.45 (0.59)
	95% CI	Lower	4.12	4.21
		Upper	5.66	4.69
Curve	Mean(SD)		10.70 (2.86)	9.76 (2.87)
	95% CI	Lower	9.56	8.61
		Upper	11.85	10.91

Mean Task time (Table 3) increased as driving demand increased. There was no interaction effect and no main effect of simulator fidelity. Mean secondary task time varied significantly with road type F (1, 23) = 92.72, $p < 0.001$.

Visual Attention Allocation

Compared to the straight road, visual attention allocation was consistently lower for the curve road condition, as seen in Table 4.

Table 4 Visual Attention allocation by Road Type and Simulator Fidelity

Road Type	Visual Attention allocation (%)		Simulator Fidelity Low	Medium
Straight	Mean(SD)		87.77 (31.78)	87.00 (20.08)
	95% CI	Lower	74.93	78.96
		Upper	100.62	95.03
Curve	Mean(SD)		31.78 (13.52)	31.66 (12.43)
	95% CI	Lower	26.37	26.69
		Upper	37.19	36.63

A main effect of road type was shown on visual attention allocation F (1, 23) = 189.44, $p < 0.001$, with the total task completion time resulting in significantly lower visual attention (i.e. less by 55.66%, $p<0.01$) on curve roads. There was no main effect of simulator fidelity and no interaction.

Speed and Speed Variability

Regarding longitudinal control, there was no main effect of simulator fidelity on speed and speed variability, indicating that drivers' speed choice was similar across both simulators. In addition there was no significant interaction on both measures. The main effect of road type was, however, significant on speed F (1, 23) = 20.95, $p < 0.001$ and speed variability F (1, 23) = 4.49, $p < 0.05$.

Significantly higher speeds were recorded on the straight road compared to the curve road (shown in Table 5), with mean difference = 2.36 mph. Similarly, the curve roads generated lesser speed variations (Mean difference = 1.06) compared to straight roads.

Table 5 Mean speed and speed variability by Road Type and Simulator Fidelity

Road Type			Simulator Fidelity: Low Speed (mph)	Medium Speed (mph)	Low Speed Variation (mph)	Medium Speed Variation (mph)
Straight	Mean(SD)		50.39 (2.77)	50.26 (2.29)	4.05 (2.68)	4.01 (2.80)
	95% CI	Lower	49.28	49.35	2.98	2.89
		Upper	51.50	51.18	5.12	5.12
Curve	Mean(SD)		47.58 (4.56)	48.39 (3.82)	2.93 (1.72)	3.01 (1.31)
	95% CI	Lower	45.75	46.86	2.25	2.48
		Upper	49.40	49.92	3.62	3.54

Lane deviation and Lateral position variability

An ANOVA on the number of lane departures revealed a significant main effect of road type F (1, 23) = 83.57, $p < 0.001$ and simulator fidelity F (1, 23) = 10.31, $p < 0.05$ and a significant interaction effect F (1, 23) = 5.10, $p < 0.05$. Examination of the results showed that drivers found it harder to maintain lane position and this effect was exaggerated in the curve road condition. For road type, a significantly greater number of lane departures were recorded on curve roads (mean difference > 2.6 for most drivers, $p < 0.001$) compared to straight roads. For simulator fidelity, a greater number of departures were recorded in the low fidelity simulator compared to the medium fidelity situation (shown in Table 6).

Table 6 Lane deviation and Lateral variability by Road Type and Simulator Fidelity

	Road Type		Simulator Fidelity: Low Lane Deviation (n)	Medium Lane Deviation (n)	Low Lateral variability (ft)	Medium Lateral variability (ft)
Straight	Mean(SD)		0.33 (0.70)	0.04 (0.20)	0.84 (0.25)	0.66 (0.19)
	Frequency		8	1		
	95% CI	Lower	0.05	-0.04	0.74	0.59
		Upper	0.61	0.12	0.93	0.73
Curve	Mean(SD)		3.58 (2.52)	2.08 (1.21)	1.08 (0.27)	1.17 (0.39)
	Frequency		86	50		
	95% CI	Lower	2.58	1.60	0.97	1.01
		Upper	4.59	2.57	1.19	1.32

Mean lateral variability (shown in table 5) differed for the main interaction effect F (1, 23) = 6.44, $p < 0.05$, indicating that variations in lateral position were significantly different across the simulators on road type. Lateral variability also differed significantly for road type F (1, 23) = 35.45, $p < 0.001$ but not for simulator fidelity. Deviations across curve roads were significantly greater than straight roads (Mean difference = 0.38).

Self-reported driving performance

A within-subjects t-test revealed a significant difference $t\ (23) = 3.61,\ p < 0.001$ on drivers reported overall driving performance. Drivers reported their performance was significantly better in the medium-fidelity (mean = 3.33) compared to the low-fidelity simulator (mean = 2.25).

Discussion

This paper reports findings from a study comparing driver visual behaviour, time sharing and performance measures, to determine the degree of attention drivers place on primary and secondary tasks between two simulators of varying levels of fidelity. The results support such research findings and theoretical models which suggest that drivers adjust their visual sampling pattern in order to acquire adequate road and non-driving task information.

In this study, the increasing primary task demand (driving from a straight road to a curve road), together with the demand of the secondary task, prompted drivers to adopt a time sharing strategy to perform the secondary task whilst seeking to maintain driving performance. From the results, drivers decreased their visual attention allocation and glance durations, whilst increasing glance frequency towards the in-vehicle display, with corresponding increases in secondary task time. As predicted, single glance durations away from the road view were significantly reduced (on average 0.8-0.9 seconds less) on curved roads compared to straight roads. Similarly, visual attention allocation to the in-vehicle tasks was reduced on curve roads. Glance frequency was significantly higher – typically, about 8 glances greater - on the curve road compared with straight roads. Taken together, such differences suggest that drivers adapted their overall visual behaviour for acquiring in-vehicle display information when the attentional resources available for completing the primary driving task changed. Such behaviours are typical of real-world observations reported in the literature (e.g. (Wikman et al., 1998). The resultant effect of this visual sampling behaviour with the in-vehicle task was evident in the higher secondary task times on the curve roads compared to the straight roads.

The effect of increasing driving demand was also reflected in differences in driving performance. Compared to the straight-road condition, drivers' mean speed on the curve roads was significantly reduced (~2mph lower on average). In addition, drivers exhibited significant detrimental performance on lateral position maintenance. Lane departure and mean lane position deviations were significantly higher on the curve road in comparison to the straight road. The workload imposed by the in-vehicle task together with the increasing driving demand resulted in significant behavioural and performance changes. Furthermore, drivers appeared to adapt their driving performance to the increased workload by reducing speed.

Adaptive Behaviour

One aim of this study was find out how drivers self-regulate their driving behaviour to either prioritise or accommodate any decrease in attention in performance caused by a secondary task. The results reveal that drivers employed a number of adaptive behaviours from strategic through to the operation levels.

At the strategic level, the various changes in visual behaviour when driving on the curve versus straight road highlight that driver moderate interaction with an in-vehicle display. Collectively, these results support the Wierwille (1993) model of drivers' need to return vision to the road when faced with increases in time pressure and forward spatial scene uncertainty resulting from driving from straight to curve road. Indeed, it is noteworthy to mention that some drivers on occasion chose to have minimal interaction on the in-vehicle task on the curve roads. Thus, overall, drivers chose to prioritise the acquisition of road information regardless of the distraction imposed by the in-vehicle visual task. These results also confirms the Senders et al. (1967) theory of drivers visual sampling and the tendency of drivers to acquire more road information when the minimum threshold of information stored in working memory is reached.

At the operational level, the results shows that, drivers decreased their speed, made more lane departures and modified the amount of attention given to the driving and in-vehicle task. Driver's adjustment of the relative amount of attention given to driving and in-vehicle tasks – characterised by reduced visual attention allocation and increasing secondary task time from straight to curve roads – was very noticeable. Regarding, driving performance, observed adaptive behaviour can be explained by Wickens and Hollands (2000) performance-resource-function (PRF shown in figure 3). The PRF focuses on task demands and the amount of attention resource a person allocates to the performance of two concurrent tasks to demonstrate adapted behaviours. From figure 3, it is clear that the more difficult the primary task (A-C), the greater the performance decrements when performing a secondary task.

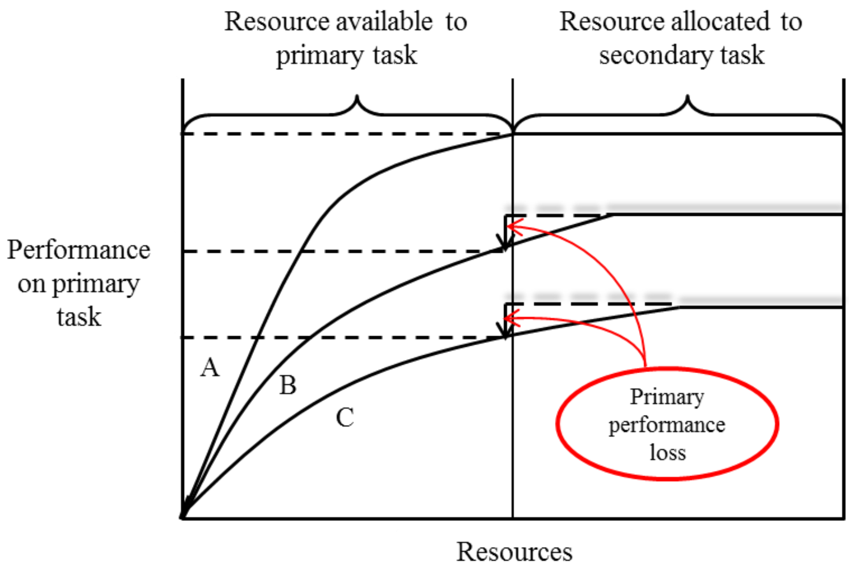

Figure 3 **Relationship between resource allocation and performance resource function (based on Wickens and Hollands, 2000)**

The results suggest that the observed driving performance decrements (red-circled) i.e. reductions in speed, greater lane departure - while performing the in-vehicle tasks was primarily due to the workload imposed by the increasing driving demand and the in-vehicle task. When the attentional resource available for driving demand was low (driving on the straight road), the resources allocated for in-vehicle task performance was greater and hence, the lower lane departure and lower secondary task times. When the driving demands were more difficult (driving on the curve road), some drivers chose either to carry out the two tasks concurrently with degraded performance on either task, or one, when the demand of the two tasks exceeded their available resources. Drivers operating on B and C PR levels thus accepted a reduced level of driving performance in an effort to maintain a satisfactory dual task performance. Others, who relinquished one task (predominantly the secondary task) and invested all of the available resources in the driving task, had to adjust their performance goals to focus on driving. These behaviours concur with previous studies (e.g. (Horberry et al., 2006, Greenberg et al., 2003, Haigney et al., 2000). The broader implications of such risk exposure and task-adaptive behaviour are discussed in a detailed review by Wilde (1994).

Predicting Validity

The results establish the face validity of using a concurrent in-vehicle task together with an increasing driving task demand scenario. The attentional demand imposed by in-vehicle task was associated with changes in driving behaviour and performance, and, importantly drivers perceived and reported these changes according to their ratings on overall driving performance. Generally, the results show a comparable direction change in drivers' visual behaviour recorded in the low and medium fidelity simulators. Driving performance - speed, speed variability and deviations in lane - was also similar in magnitude and direction.

The importance of Simulator Fidelity

Stanton (1996) reports that the physical and psychological fidelity of simulators are the most important when addressing driving simulator fidelity issues. In terms of physical fidelity, the low and medium-fidelity simulators considered in this study varied on a range of dimensions related to the multi-sensory experience. These differences in the two simulators were evident in the driving behaviour measures reported. Although similar results were observed across simulators, none of the measures were absolutely identical. In terms of visual behaviour, the interaction effect of glance duration showing a greater difference in the medium compared to low-fidelity simulator suggests that, the medium-fidelity simulator was more effective at eliciting effects of task demand on glance duration. Similar effects were shown for lateral control variables. The observed poor lateral control (greater lateral position variation and lane departures) in the low-fidelity simulator suggested that drivers experienced difficulty in controlling the vehicle, even in the straight road condition. Similar effects were shown by Jamson and Jamson (2010) and are perhaps related to the lack of field of view and reduced feedback from the vehicle controls in the low-fidelity situation. This lack of vehicle control also affected drivers' overall performance ratings. It is proposed that the limitations of a low fidelity simulator i.e. features which may include reduced field-of-view, reduced vehicle control feedback should be considered appropriately especially in simulator investigation where the focus is on creating a comparable simulator-road data and inferences. In investigations such as equipment validation, acquisition of high order vehicle control skills, situation awareness and risk perceptions, the low fidelity simulator should be supplemented with a more advanced simulator

Conclusions

In summary, we explored how drivers prioritise primary and secondary tasks within simulators as an approach to validating driver behaviour and performance measures in distraction studies. Driver visual behaviour and performance measures from a low and medium-fidelity were compared to test their consistency with measures reported in well-established theoretical and on-road research. Results show that, drivers as a whole showed visual sampling behaviours and secondary task performances consistent with well-established on-road research. The change in driving demand affected driving performance and subjective overall performance. Drivers also exhibited inherently different attention and time-sharing strategies. Various adaptive/compensatory behaviours were elicited by drivers to compensate for changes in the demand of the driving task. For instance, a number of drivers opted for reduced primary driving performance, whilst others relinquished the in-vehicle task. Such behaviours are typical of drivers in the real world and could inform research into drivers' self-regulated behaviour with distracting interfaces.

In terms of simulator fidelity, there were no apparent differences in drivers' time-sharing/prioritisation strategies. Participants exhibited poorer lane keeping performance in the low-fidelity simulator, most likely linked to its' basic controls and visual environment, rather than any variations in how drivers prioritised primary/secondary tasks. As such, a low-fidelity simulator could play a significant role in distraction research, but their limitations should be considered when generalising results.

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