Speed choice and hazard perception in complex urban road environments with and without on-street parking

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Abstract
Crash risk varies across roads within the same speed zone. There may be environmental factors not currently captured in the speed limit setting process that, if taken into account, would improve the safety of some higher-risk roads. To improve the speed-limit setting process, it is necessary to understand how drivers' travel speeds and other risk-relevant behaviours are affected by features of the road environment. The present study examined the extent to which drivers' travel speeds and hazard perception ability are affected by on-street parking, a common feature of urban road environments. Twenty-nine participants drove a simulated urban commercial route with no parking bays, empty parking bays, and parking bays occupied by cars, plus a less-complex 'arterial' road with no parking bays. While driving they performed a safety-relevant peripheral detection task. Each environment also included an unexpected event in which a pedestrian suddenly crossed the road in front of the subject vehicle. Vehicle speeds were slower in the presence of occupied on-street parking bays compared to the other two environments; however, the speed reduction was insufficient to compensate for observed impairments in drivers' hazard perception and slower response to the pedestrian in this condition. Lower speed and longer response times also resulted from increased background visual complexity (in the commercial compared to arterial No Parking condition) in the absence of on-street parking bays or cars. Implications for policy are discussed.

Keywords:
Driving simulation, driving task difficulty, human factors, visual complexity

Introduction
Driver speed is a major determinant of crash risk (e.g. Kloeden, McLean, & Glonek, 2002). Road engineers attempt to control speeds by setting speed limits, based on a number of road factors (for details see Rudin-Brown & Lenné, 2010). Observed crash data show high variability in crash risk across sites within the same speed limit zone (MUARC, 2004). Assuming that speed limits aim to achieve relatively uniform and low crash risk (while maintaining mobility), this suggests that there may be sources of crash risk not captured in the current process of setting speed limits.

In addition to the stated speed limit and a driver's motivation to comply with it, travel speed is influenced by characteristics of the road environment such as optic flow (Denton, 1980), road width (Martens, Comte, & Kaptein, 1997), building setback (van der Horst & de Ridder, 2007), building height (Allsop, 1995; Elliot, Mccoll, & Kennedy, 2003), and visual complexity (Horberry, Anderson, Regan, Triggs, & Brown, 2006). These factors are likely to influence drivers' subjective workload and perceived task difficulty, which have been posited to moderate speed control (e.g. Fuller, McHugh, & Pender, 2008; Hoyos, 1988). The existence of 'black spots' (locations with high crash frequencies relative to the remainder of the road network) suggests that drivers are not able to perfectly assess task difficulty and compensate effectively by lowering their speed (otherwise crash risk would be uniform across the road network, regardless of the road environment and corresponding difficulty of the driving task).

The current project aimed to examine individual driver behaviour in the presence of a road environment feature that increases crash risk, to assess the level of compensation and determine whether modified speed limits might reduce crash risk. The road environment feature examined was on-street parking, which has been found to be associated with increased crash risk in several studies (Greibe, 2003; Pande & Abdel-Aty, 2009; Roberts, Norton, Jackson, Dunn, & Hassall, 1995). The research setting was a driving simulator, as previous research suggests that simulation is a safe and low-cost method to provide surrogate measures of crash risk (Rudin-Brown & Lenné, 2010). Dependent variables included vehicle control, performance on a peripheral detection task (PDT), and response to a critical situation (in which the driver will collide with a simulated road user unless they take preventive action). It was hypothesised that on-street parking would lead to increased subjective workload, decreased vehicle speed, increased speed variability, changes in lateral position, possibly increased lane position variability, increased response time to safety-relevant PDT targets and more missed targets, and impaired responses to an unexpected pedestrian event.

Method

Participants

Twenty-nine drivers (15 male) aged between 20 and 53 years (mean = 28.0 years) were recruited from the University community via an online advertisement. The average number of years participants had been driving was 9.8 (SD = 8.0). All participants were regular drivers with at least one year of driving unsupervised. Participants were compensated $30 for their time.

Equipment and Scenarios

The experiment used MUARC's Portable Driving Simulator, an EF-X by Eca-Faros with modified software for research purposes. This consists of a driver's seat with dashboard, steering wheel, accelerator and brake pedals, handbrake and gear shift. The simulated environment is displayed on three screens providing 120° field of view including rear view mirror. Data is collected at 30hz.

The simulated road had two lanes in each direction, with pedestrians on footpaths on both sides, and occasional oncoming traffic. There were four conditions: one 'Arterial' type road, and three Commercial (shopping-strip style) roads with shopfronts close to the road. The three Commercial roads contained either no parking bays (No Parking), empty parking bays (Empty Parking), or parking bays 90% occupied by vehicles (Full Parking). In one block of buildings for each condition, a pedestrian suddenly walked onto the road in front of the subject vehicle. The Arterial condition had the same road geometry (two lanes, same width, same traffic) as the Commercial roads, but buildings were fewer, set far back from the road and there were no parking bays and no parked cars; there was no critical situation (unexpected crossing pedestrian) in this condition.

Procedure

After completing a demographic and driving experience questionnaire, participants performed a short practice drive to familiarise themselves with the simulated vehicle. Participants were instructed to practise accelerating, braking, and driving at a consistent speed of 60 km/h. This drive was repeated with the addition of the peripheral detection task (PDT), which involved pressing the left or right indicator in response to an icon of a pedestrian that appeared at the far left or right sides of the screen. The icon appeared at randomized intervals of 200, 300, 400, 500 or 600m (12-36 sec at 60kph) and disappeared after 100m (6sec) unless the driver responded before then. For the three main drives, participants were told that the speed limit was 60km/hr, and they were instructed to remain in the centre lane but otherwise drive as they normally would while responding to the PDT. Each drive consisted of eight 1km long blocks with the four conditions in random order, plus Arterial blocks at the start and end. The order of the three main drives was counterbalanced across participants. At eight points during the three drives, participants stopped at a red traffic light and rated mental demand, time pressure, success, effort, frustration, and safety (reverse scored) during the block they had just driven though; these scores were summed to give a workload rating out of 60. The whole experiment took just over an hour.

Data analysis

Each of the dependent variables was analysed using a repeated-measures analysis of variance (RM ANOVA) with the within-subjects factor of condition (Arterial, No Parking, Empty Parking, Full Parking). The first and last 200m of data from each block were discarded to avoid the effects of stopping for red traffic lights where these were present (all blocks were 'trimmed', whether or not they contained a traffic light at the start or end, so that the same amount of data was available for comparison between blocks).

Results

Speed

The main effect of parking condition was significant for mean speed, $F\,(3,69) = 76.70$, $p < .001$, η^2 (effect size) = .769[1]; maximum speed, $F\,(3,69) = 24.81$, $p < .001$, $\eta^2 =.519$; and speed variability, $F\,(3,69) = 183.81$, $p < .001$, $\eta^2 = .889$. Mean and maximum speed decreased as the complexity of the environment increased (Figure 1): the Arterial and Full conditions were significantly different from the other two conditions, while the No Parking and Empty bay conditions were not significantly different from each other. Speed variability increased with environmental complexity (Figure 1): the Arterial

[1] For clarity: the *F* value refers to the shape of the frequency distribution of values; it can only be compared with other *F* values with the same degrees of freedom (the numbers in parentheses after '*F*'). The *p* value refers to the probability of obtaining this result by chance; $p<.001$ means less than 1 in a 1000 chance of this result occurring randomly. η^2 is a measure of effect size, ranging from 0 to 1, and can be compared across different measures: e.g. the effect of parking on speed variability is greater than the effect on maximum speed.

condition was significantly lower than all other conditions, while Full Parking was significantly higher than No Parking (Empty was not significantly different from either Full Parking or No Parking conditions).

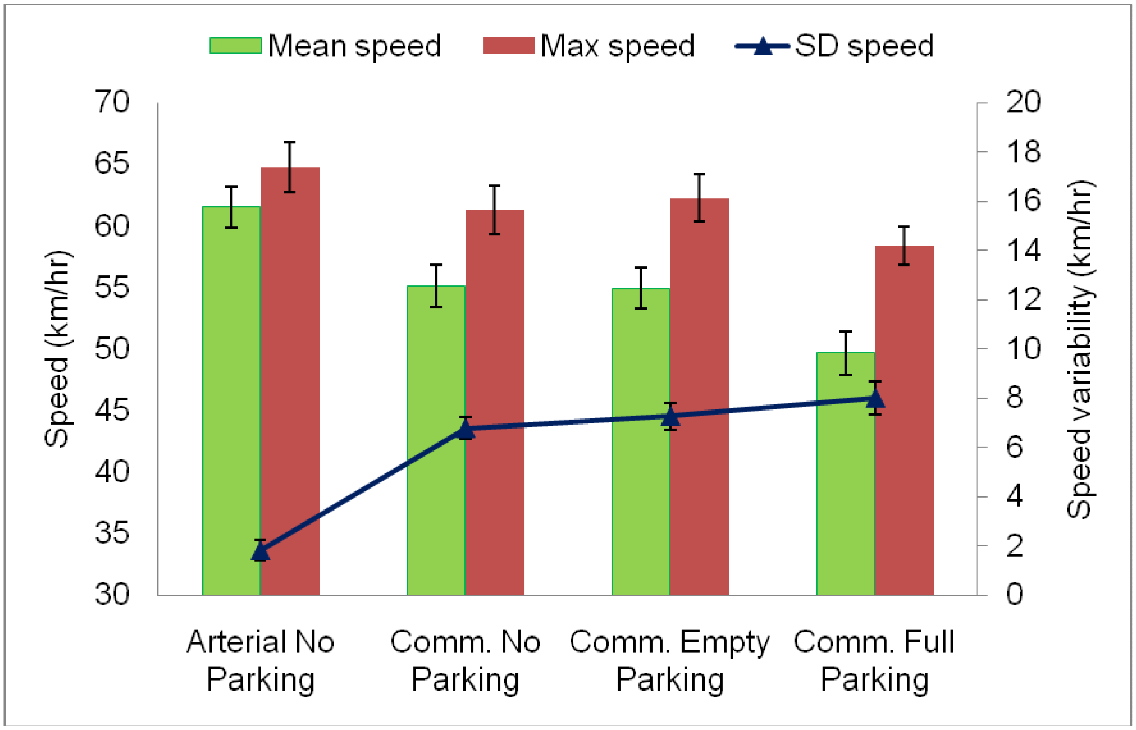

Figure 1. Mean and maximum speed and speed variability by parking condition (bars represent 95% confidence intervals)[2]

Peripheral detection task

There were only 34 missed icons out of a total of 1740 target presentations across all participants. Icons were missed predominantly in the Full Parking condition (Figure 2).

The main effect of parking condition on response time to peripheral icons was significant, $F\,(3,54) = 42.969$, $p < .001$, $\eta^2 = .705$. Pairwise comparisons showed that response time to the PDT during the Full Parking condition was significantly slower than during all other conditions, which did not differ from each other (Figure 2).

[2] The 95% confidence intervals (CIs) in the figures show the range in which the mean value would fall in 95 of 100 similar experiments with these effect sizes. When the CI is small, that means the estimate of the value is precise.

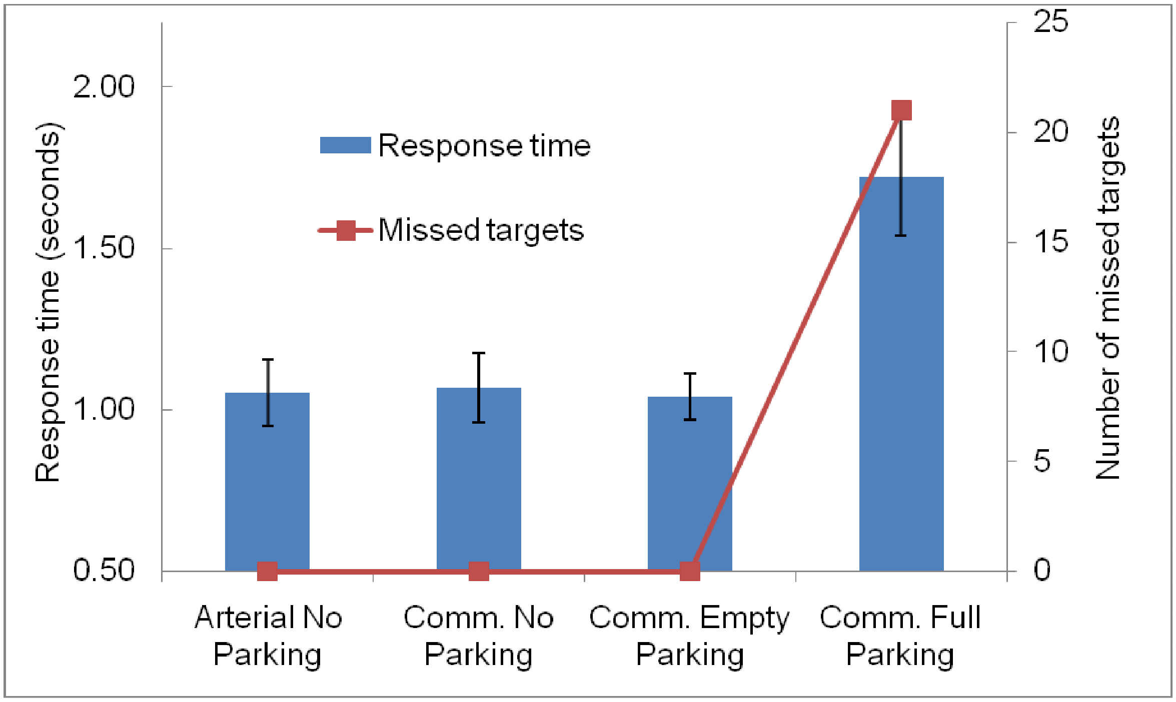

Figure 2. Number of missed peripheral targets, and response time to peripheral icon by parking condition (bars represent 95% CIs)

Response to unexpected pedestrians

Dependent measures of participants' responses to the unexpected pedestrian event were: time to accelerator release, time to brake, maximum brake pressure, minimum time to collision, minimum distance to the pedestrian, and whether or not the participant's vehicle collided with the pedestrian. The first five of these were included in a repeated measures multivariate ANOVA (MANOVA). The main effect of parking condition was significant, $F(10,86) = 5.684$, $p < .001$, $\eta^2 = .463$; and univariate analyses showed that it was significant for every measure. Table 1 presents the results of the analyses. In every case, there was a significant difference between the Full condition and the No Parking/Empty conditions, which do not differ from each other.

Table 1. Response to unexpected pedestrian event

Measure	$F(2,46)$	p	η^2	Difference
Time to accelerator release	45.266	<.001	.715	Full > No park / Empty
Time to brake	28.024	<.001	.609	Full > No park / Empty
Maximum brake pressure	10.201	<.001	.362	Full > No park / Empty
Minimum distance	17.102	<.001	.487	Full < No park / Empty
Minimum time-to-collision	17.019	<.001	.486	Full < No park / Empty
Number of collisions	$\chi^2(2)= 21.46$	<.001		Full > No park / Empty

There was only one collision during the Empty Parking block, after which the driver said that he had seen the pedestrian (and braked) but expected that the pedestrian would stop, so had not come to a full stop. There were no collisions during the No Parking block, while 11 of the 29 drivers collided with the pedestrian during the Full Parking block.

Figures 3 and 4 present responses to the unexpected pedestrian event by parking condition. It can be seen that responses are slower and more intense in the Full parking condition than other conditions, and that the vehicle stops closer to the pedestrian.

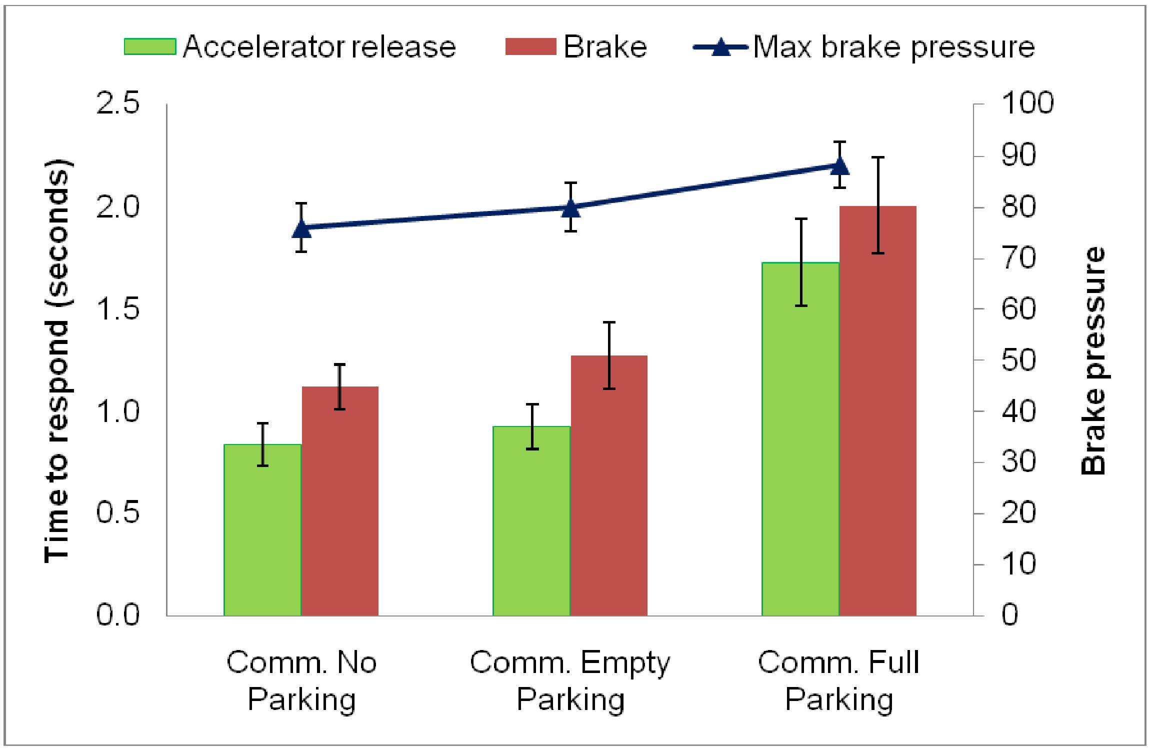

Figure 3. Responses to unexpected pedestrian road-crossing event (bars = 95% CIs)

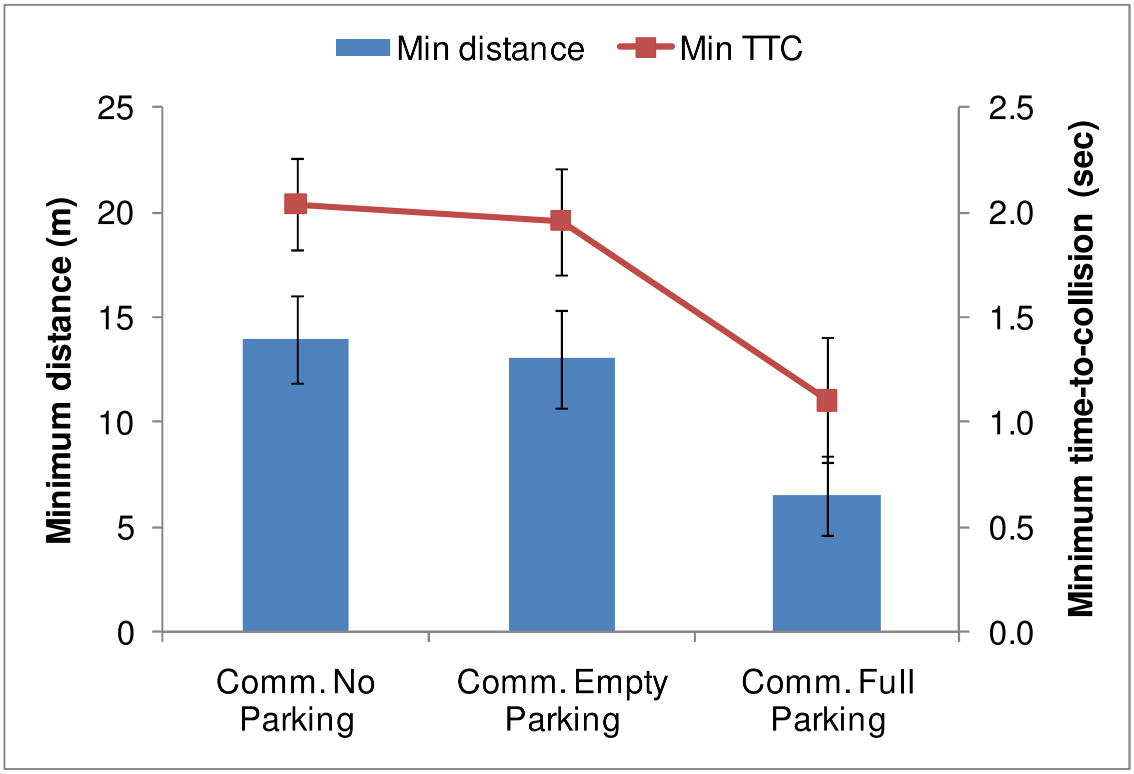

Figure 4. Minimum distance and time-to-collision with pedestrian (bars = 95% CIs)

Lateral position

The effect of parking was significant for mean lateral position, $F\,(3,54) = 87.094$, $p < .001$, $\eta^2 = .829$. Pairwise comparisons showed that participants drove significantly closer to the left (kerbside) edge in the Arterial condition and significantly further from the kerb in the Full condition, with the No Parking and Empty conditions in between these extremes. Figure 5 demonstrates these results.

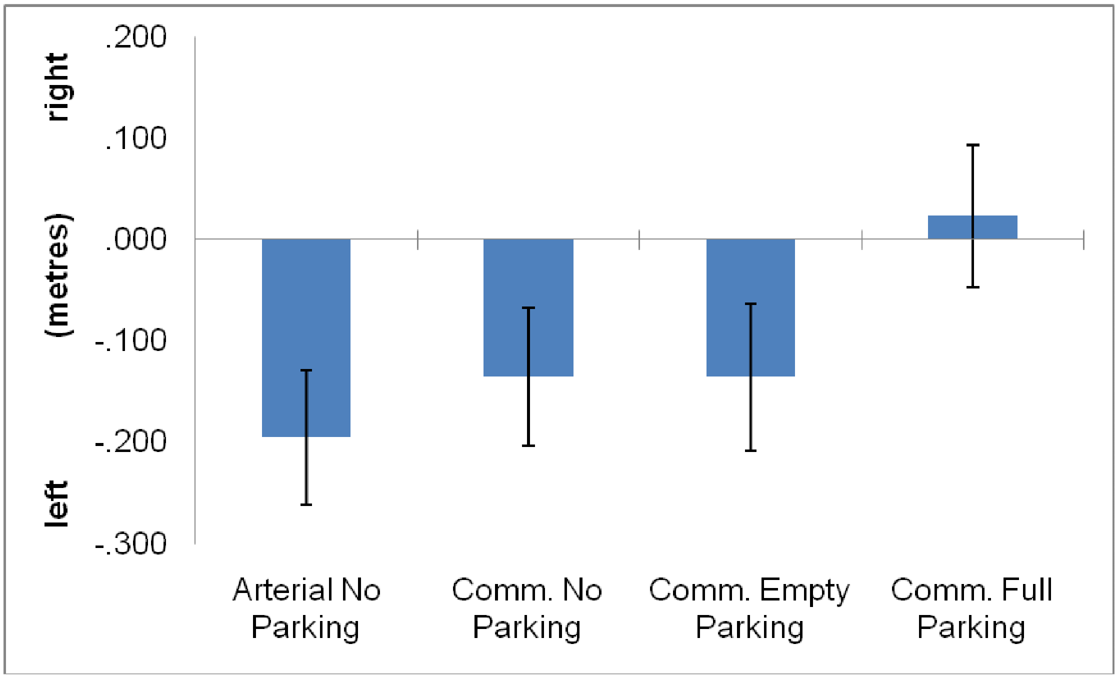

Figure 5. Mean lateral position by parking condition (bars represent 95% CIs)

For lane position variability, there was no significant main effect of parking.

<u>Workload</u>
The effect of parking was significant, $F\,(3,54) = 9.208$, $p < .001$, $\eta^2 = .338$. Pairwise comparisons showed that workload in the Arterial condition was significantly lower than in all other conditions, and all other conditions were not significantly different from one another (Figure 6). However the difference between the Full and Empty parking condition was close to significant (p=.068) and may have been significant if not for the large variance in reported workload in the Full parking condition (variance = 92.5 for Full parking, compared to 62.4 for Arterial, 67.4 for No Parking, and 65.8 for Empty parking).

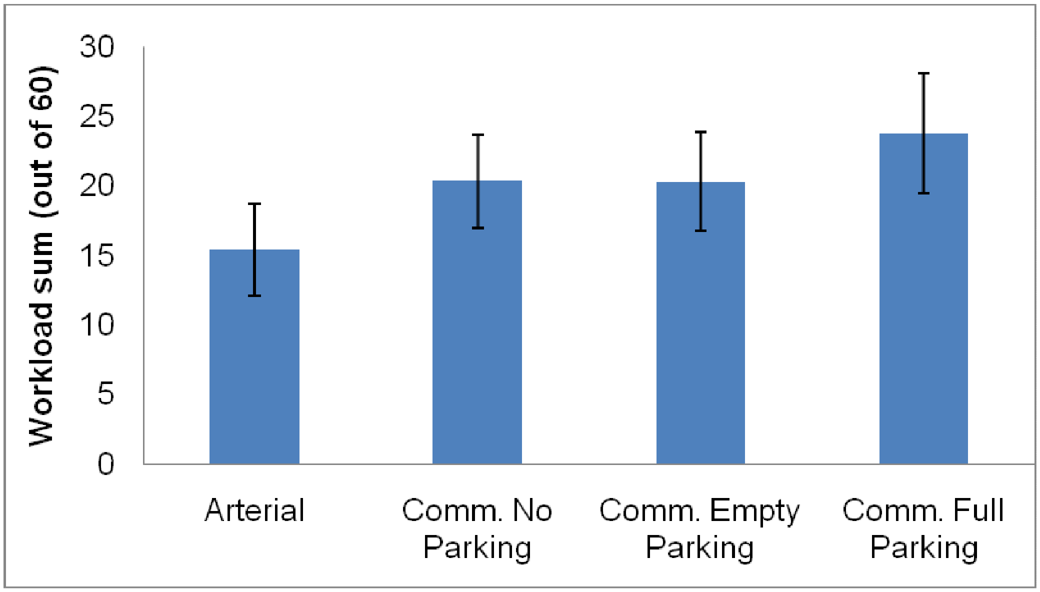

Figure 6. Workload ratings by parking condition (bars represent 95% CIs)

Discussion

As expected, vehicles parked on-street in a complex, urban environment influenced driver behaviour in several ways: drivers reduced their vehicle speed, positioned the vehicle further from the kerb towards oncoming traffic, reacted more slowly to a peripheral target, and responded more slowly to a pedestrian unexpectedly crossing the road when driving in the Full parking condition compared to the Empty condition. Although there was evidence of some compensation by drivers in response to the changed environment in terms of reduced speed and a change in lane position further from the parked vehicles, these changes were not sufficient to protect drivers from an increase in crash risk (as measured by response to the unexpected pedestrian event). The combination of behaviour changes seen in the driving simulator is therefore likely to translate to higher crash rates in real world, urban areas where vehicles are parked on-street.

There were no significant differences between the No Parking and Empty Parking conditions. These conditions were identical except for the presence of road markings implying that vehicles were permitted to park on the street. Drivers in the present study were never directed to park, so it appears that they interpreted these markings as being irrelevant in the absence of any vehicles actually parked there. This is consistent with previous research that found that speed is not affected by similar markings such as bus lanes and cycle lanes unless they are occupied (Elliot et al., 2003). Parking bay markings are thus not likely to be a successful traffic calming measure, and when bays are occupied the crash risk is elevated beyond the level compensated for by speed reductions.

A number of performance measures showed changes between the Arterial condition (where buildings were few and set far back from the road, and the roadside environment was simple) and the No/Empty Parking condition (where the roadside environment was visually complex, comprising continuous shopfronts at a small distance from the road edge). In the latter condition, subjective workloads were higher, speed was lower and more variable, and lateral position was further away from the road edge. These are the same effects as those found when comparing No/Empty Parking to the Full Parking condition, but larger. This result implies that not only characteristics of the road itself, but the visual complexity of the roadside environment is an important contributor to driver workload and performance. This may reflect drivers anticipating the potential activity of pedestrians in commercial environments, or the contribution of purely visual components of a complex environment (such as increased optic flow), or some combination of these effects.

Response time to both the safety-relevant PDT and the unexpected pedestrian event remained greater in the Full parking condition, despite the slower speeds in this condition. For example, mean time to brake in the Full parking condition was 2.0 sec compared to 1.1 sec in the No Parking condition. At the mean speed for the Full parking condition of 50 km/hr, this difference translates to 12.5 extra metres travelled before the vehicle even begins to decelerate. These results might be even more dramatic for road users with slowed perception-response times, such as older or inexperienced drivers. This suggests that speeds would need to be even lower to ensure that all road users were capable of stopping before an unexpected hazard such as a pedestrian crossing from between parked vehicles. The present results support the use of lower variable speed limits in shopping centres during peak times when vehicles are likely to be parked on-street.

A limitation of the study is that it was performed in a low-fidelity driving simulator that lacked the full complement of perceptual speed cues (e.g., visual flow in far peripheral vision). Such cues may help drivers on real roads slow down more in conditions of high roadside object density and low pavement width, such as the Full Parking condition in the present study. Ideally, future research would include a wider field of view, and/or be performed either in a higher fidelity simulator on on-road, to determine if the observed effects were of the same magnitude. However, the fact that the present study showed behaviour modification in the absence of these cues is a testament that useful results can be obtained even without the highest degree of simulator fidelity. For further discussion on the validity and applicability of simulator results and tasks such as the PDT, please see Rudin-Brown and Lenné (2010).

The present study examined driver behaviour under the instruction to drive at 60km/h (the speed limit for most connector roads in Australian cities). It would be useful to understand how drivers adapt to on-street parking under different speed restrictions (i.e. speed limits). Further research could also examine whether traffic calming devices and/or visual treatments can successfully change behaviour to match risk levels posed by factors such as on-street parking.

Acknowledgements

This project was funded through the MUARC Baseline Research Program. The authors would like to thank the program sponsors for their support, and Karen Stephan for contributing to the study design and commenting on the paper.

References

Allsop, R. (1995). *Reducing Traffic Injuries Resulting From Excess and Inappropriate Speed*. Brussels: European Transport Safety Council

Denton, G. G. (1980). The influence of visual pattern on perceived speed. *Perception, 9*(4), 393-402.

Elliot, M. A., Mccoll, V. A., & Kennedy, J. V. (2003). *Road design measures to reduce drivers' speed via 'psychological' processes: A literature review* (No. TRL564): Transport Research Laboratory

Fuller, R., McHugh, C., & Pender, S. (2008). Task difficulty and risk in the determination of driver behaviour. *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology, 58*(1), 13-21.

Greibe, P. (2003). Accident prediction models for urban roads. *Accident Analysis & Prevention, 35*, 273-285.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185-191.

Hoyos, C. G. (1988). Mental load and risk in traffic behaviour. *Ergonomics, 31*(4), 571-584.

Kloeden, C. N., McLean, A. J., & Glonek, G. (2002). *Reanalysis of Travelling Speed and the Risk of Crash Involvement in Adelaide, South Australia* (No. CR 207): Road Accident Research Unit, University of Adelaide, for Australian Transport Safety Bureau

Martens, M. H., Comte, S., & Kaptein, N. A. (1997). *The effects of road design on speed behaviour: a literature review*: TNO Human Factors Research Institute

MUARC. (2004). *Review of Speed Zone Guidelines Stage 1 and Stage 2*: Unpublished consultancy report to VicRoads

Pande, A., & Abdel-Aty, M. (2009). A novel approach for analyzing severe crash patterns on multilane highways. *Accident Analysis & Prevention, 41*(5), 985-994.

Roberts, I., Norton, R., Jackson, R., Dunn, R., & Hassall, I. (1995). Effect of environmental factors on risk of injury of child pedestrians by motor vehicles: a case-control study *British Medical Journal, 310*, 91-94.

Rudin-Brown, C., & Lenné, M. (2010). *Driving simulation to support road safety policy: Understanding crash risks to better inform speed setting guidelines*. Paper presented at the Australasian Road Safety Research, Policing and Education Conference.

van der Horst, R., & de Ridder, S. (2007). Influence of roadside infrastructure on driving behavior: driving simulator study. *Transportation Research Record, 2018*(2018), 36-44.