Accident Analysis and Prevention 122 (2019) 76–84

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Mind wandering during everyday driving: An on-road study

Bridget R.D. Burdett*, Samuel G. Charlton, Nicola J. Starkey

Transport Research Group, University of Waikato, Hamilton 3240, New Zealand

ARTICLE INFO

Keywords:
Mind wandering
Everyday driving
Attention
Context regulation
Thought sampling

ABSTRACT

This study was an investigation into mind wandering during everyday driving, and its association with crash patterns. We selected a 25 km route on urban roads for analysis of crashes, and an on-road study of mind wandering by a sample of drivers familiar with the route. We analysed reported crashes on the route over a five year period from New Zealand's crash database. For the on-road study a researcher accompanied 25 drivers on the route, asking them what they were thinking about at 15 predetermined road sections. The road sections were selected to include a range of different speed limits and traffic volumes as well as roundabouts, priority intersections and midblocks. Thought samples were categorised as either mind wandering or driving focus, and triggered by the senses, or internally. The frequencies of mind wandering at different road sections on the route were compared to the frequencies of reported crashes along the same route over the preceding five years. Results showed that although all drivers reported mind wandering, it was more likely to be reported at slower, quieter, less complex road sections. Overall, more crashes were reported at priority intersections and midblocks than at roundabouts, but the crash rate (per road section) was higher at roundabouts, where mind wandering was least likely to be reported. These findings suggest that although drivers' minds wander constantly, driving focus is commanded in demanding situations and in response to the actions of other road users. While mind wandering is ubiquitous, drivers are least likely to report mind wandering at locations showing the highest crash rates. More work is needed to test these findings and to provide direction for road safety interventions.

1. Introduction

Mind wandering (MW) is a common experience in everyday life. People readily report MW, defined as task-unrelated thought (Smallwood and Schooler, 2006) during both laboratory situations and daily activities (Mooneyham and Schooler, 2013; Smallwood and Schooler, 2015). Experience sampling studies, in which participants are interrupted during their daily life and asked to report their thoughts, have found that MW is reported on between one quarter and half of all responses (Killingsworth and Gilbert, 2010; Song and Wang, 2012; Spronken et al., 2016).

MW is also common during driving. We have previously asked drivers how often they experience MW across a range of different driving situations, such as on familiar and unfamiliar roads, and in their own or an unfamiliar car. Our results revealed that all drivers report experiencing MW at least occasionally, and we found that drivers were most likely to experience MW driving their own car on familiar roads (Burdett et al., 2016).

The link between MW and route familiarity has been corroborated by others. With repeated practice on a simulated route, drivers report more MW (Yanko and Spalek, 2013), and show an increasing tendency to report "'driving without thinking about it', 'zoning out' or 'going on autopilot'" (Charlton and Starkey, 2011, p131). Drivers also report reduced awareness during familiar drives such as the daily commute (Handy et al., 2005; Papp et al., 2004; Steinberger et al., 2016). Respondents in a survey by Berthié et al. (2015) estimated that their mind wandered for an average of 35% of the time during their most recent (real-world) drive, but if that drive was a commute, they were more likely to report a higher proportion of time spent MW.

In an earlier study we explored how drivers experience MW during their daily commute, given that it appears to be the drive where MW is most likely to be experienced. Eleven female participants were asked what they were thinking about (a descriptive experience sampling procedure) between four and six times across each of ten drives per participant. Drivers reported MW on 63% of the 587 thought samples (Burdett et al., 2018a). These findings demonstrated that MW is pervasive during the most familiar of everyday trips, and is not an exceptional or unusual experience.

The preceding section highlights that MW is a common experience during everyday driving but its link with crashes is unclear. Intuitively it seems that MW during driving is probably 'unsafe'. Indeed, a small but growing body of research points towards a causative link between

* Corresponding author.
E-mail address: bb39@students.waikato.ac.nz (B.R.D. Burdett).

https://doi.org/10.1016/j.aap.2018.10.001
Received 24 April 2018; Received in revised form 1 October 2018; Accepted 1 October 2018
Available online 10 October 2018
0001-4575/

MW and crash risk. He et al. (2011) suggested that because MW is associated with performance decrements such as narrowed gaze patterns in driving simulation, it "might easily contribute to… …increased crash risk" (p18). In a simulated car-following task Yanko and Spalek (2013) measured response times to braking vehicles and pedestrians crossing as a function of drivers' reported MW and concluded that MW affects drivers' performance and "may therefore lead to higher crash risk" (p260). Meanwhile, Galéra et al. (2012), who interviewed drivers involved in a crash and asked them to recall what they were thinking about before the collision, resolved that MW is a dangerous and undesirable state which is "threatening safety on the roads" (p1). However, there are several reasons to question the veracity of the conclusions drawn from these studies. They all failed to account for the fact that drivers experience MW during normal everyday trips, which do not result in crashes. This is a problem because evidence from everyday driving suggests that MW is not unusual, but commonplace. If everyday driving involves so much MW, it is unclear which drivers face increased or higher crash risk, and in what situations their safety is being threatened. In addition, there is limited understanding of the association between MW during real driving, and crash patterns, so laboratory-based research that ignores everyday drivers' experiences of MW cannot reasonably be generalised outside of its experimental setting.

It is important to continue investigation into MW and crash risk within an appropriate context (i.e., on roads). There are differences in how people think about a task, and therefore how they experience MW, between the laboratory and everyday life (Kane et al., 2017). During simulated driving studies, the setting as well as the instructions given are likely to affect the way participants think, which is problematic if results about MW are to be generalised beyond the laboratory. For example, participants in the study by He et al. (2011) were "told to keep their attention on the driving task as much as possible" (p15). Instructions concerning attention are not explicit during everyday driving, and our results suggest that drivers do not set out with sustained driving task focus as an obvious goal (Burdett et al., 2018a). Therefore, continued investigation of both crashes and MW in a naturalistic driving context is important if we are to understand how MW is experienced during driving, so that we can work towards interventions that improve road safety.

In another study, we explored a potential link between MW and crash risk (Burdett et al., 2017), building on the evidence that MW is most frequently experienced on familiar roads (Berthié et al., 2015; Burdett et al., 2016). Our research into the 'close to home effect' demonstrated that for New Zealand drivers, crashes are over-represented on roads within 10 km (6 miles) of home, which are probably more familiar to drivers, on average, than roads further away (Burdett et al., 2017). Even though roads close to home are where most driving happens, New Zealand drivers are more likely to have a crash there, mile for mile driven, than on a road further away.

MW and crashes are both relatively common in familiar places, so we explored crash data on familiar roads close to home in more depth (Burdett et al., 2018b). We analysed the errors involved in crashes at different distances from home, differentiating between intentional violations, which are the result of intentional but illegal or dangerous behaviour; and lapses of attention, which are typically unintentional and may be related to MW. We found that in New Zealand, crashes close to home are commonly related to lapses of attention, whereas crashes related to intentional violations are less common. We also explored the places where crashes occur, and found that more crashes close to home happen at relatively simple midblocks (the stretches between intersections) on low-speed (urban) streets than at complex places such as roundabouts (Burdett et al., 2018b). However, it is unclear whether crashes are common at midblocks simply because they make up most of each drive, or whether the pattern may be due in part to drivers' tendency to experience MW in places where nothing risky or demanding usually happens. To date, there have been few studies of how or whether drivers regulate their attention in response to changing demands across a drive on real streets. The evidence falls short of establishing any links between MW and crash risk close to home.

As well as building on a potential link with crash risk, studying MW and driving can inform theories of driver behaviour and general theories of MW. Theories of driver behaviour have for many years assumed that drivers apply conscious focus to maintain a feeling of comfort or safety (Fuller, 2005; Fuller et al., 2008; Lewis-Evans and Rothengatter, 2009; Wilde, 1982, 1998). For example, Fuller et al. (2008) suggest that drivers consciously adjust their speed to stay within some subjective level of comfort.

In contrast with many driver behaviour models, there is growing evidence that the driving task rapidly becomes proceduralised, and does not command conscious focus much of the time (Charlton and Starkey, 2011, 2013; Harms and Brookhuis, 2016). Evidence that many aspects of the driving task (such as maintaining an appropriate speed) happen automatically and not with conscious intent led Charlton and Starkey (2011, 2013) to develop the tandem model of driver behaviour. The tandem model suggests that most of the time, an unconscious monitoring process governs safe behaviour. Conscious driving task focus is engaged only temporarily, typically in response to an unfamiliar or demanding situation. The model provides a rationale for why drivers report MW so frequently during familiar trips, because they are well-practiced and therefore less demanding than an unfamiliar trip on a similar route. More research into where drivers are relatively more or less likely to report MW, and how those situations are associated with crash risk, could help to build on models of driver behaviour.

Evidence that has informed general theories of MW also suggest that its likelihood of occurrence is linked with both task familiarity and momentary demand, but to date few studies have explored MW variation in naturalistic contexts to advance understanding of why and how MW happens. Smallwood and Andrews-Hanna (2013) proposed the Context Regulation Hypothesis (CRH), which suggests that MW is more likely in familiar or less demanding situations because they can be successfully negotiated without applied task focus. The CRH is based on evidence that MW is more commonly experienced in familiar situations of low demand, albeit most studies used to derive the theory were in laboratory settings (Smallwood and Andrews-Hanna, 2013). Driving is a useful context in which to explore and potentially build on this hypothesis, because it is familiar to many people, while also comprising situations of varying demand.

In the current study we compared crash locations from the five-year crash history of a 25 km urban road route to the locations where a sample of drivers reported MW as they drove the route with us. The route comprised situations of varying demand, such as busy intersections and quiet mid-blocks. We first examined how crashes are distributed according to the different road situations (and varying demands) on the route using New Zealand's national database of reported crashes. Second, we explored MW on the same 25 km route by recruiting drivers familiar with the route, and asking them what they were thinking about at predetermined locations. Overall we set out to compare the locations of reported crash numbers with the locations of MW on familiar urban roads.

2. Methods

2.1. The route

A 25 km road route around Hamilton City, New Zealand, was selected for a study of reported crashes, and an on-road study of drivers' reported MW (Fig. 1). The route was selected to include a range of different speed limits, roads with different traffic volumes, and a variety of intersections and midblock sections (lengths between intersections). Signalised intersections were excluded from both the study of crashes and from the on-road study of drivers' reported MW.

For the analysis of reported crashes, the route was divided into road sections with different characteristics. There were 17 roundabouts and

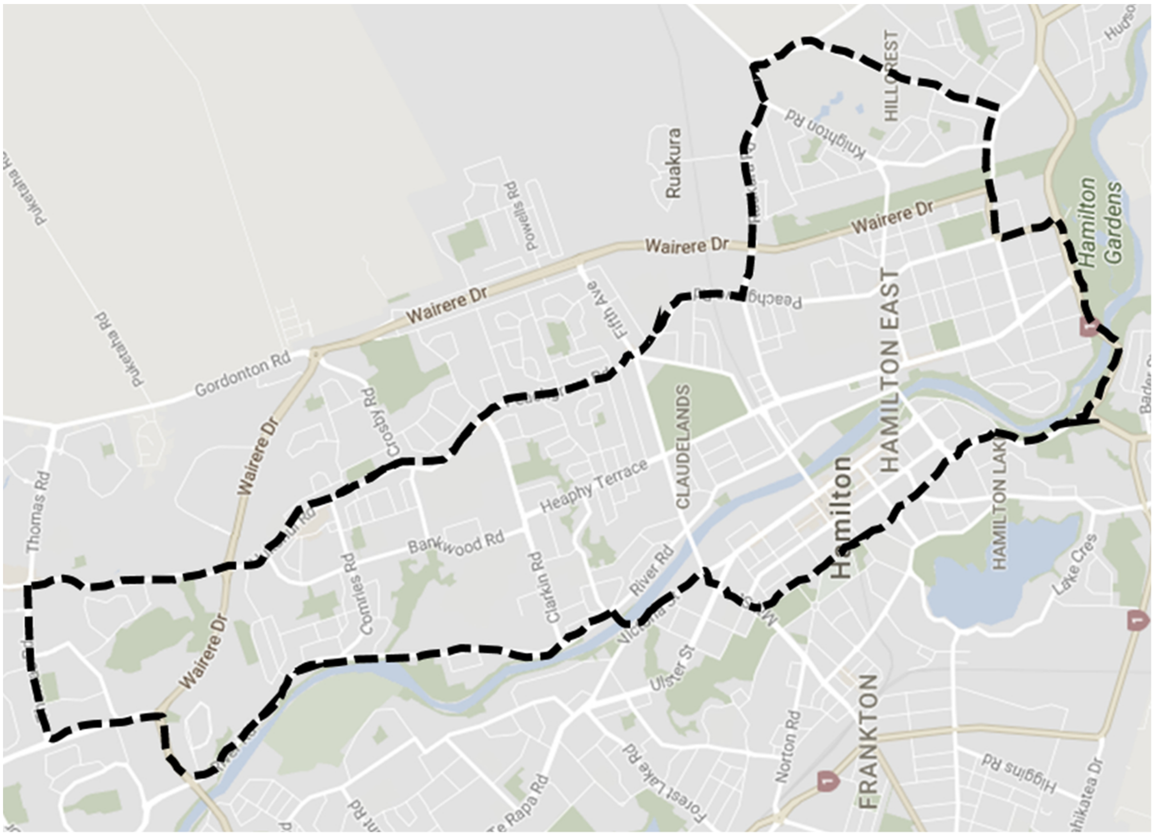

Fig. 1. The 25 km route in Hamilton, New Zealand, used to analyse reported crashes and drivers' reported MW (on-road study).

77 priority intersections in the route, which were defined as 100 m in length. There were 112 midblock sections in between intersections along the route. The lengths of midblocks ranged from 10 m to 550 m (M = 122 m). Overall therefore, the 25 km route comprised 206 defined sections (excluding traffic signals).

2.2. Crash data

Crash data were all reported injury crashes involving a driver of a car at roundabouts, priority intersections and midblocks on the 25 km route, for the five years 2012 to 2016 inclusive. Data were obtained from the NZ Transport Agency's Crash Analysis System (NZ Transport Agency, 2017). Information extracted from crash reports included the crash location (street and distance from the nearest intersection, to locate the crashes within defined road sections on the route); and for crashes at intersections, the intersection form of control (whether it was a roundabout, traffic signals, priority intersection (Stop or Give-Way controlled) or other, i.e., midblock, including crashes at driveways). Crashes at traffic signals were subsequently excluded.

The crash rate per road section (roundabout, priority intersection or midblock, as defined in Section 2.1 above) for the 25 km route was the total number of reported injury crashes per road section, per year. The crash data are summarised in Table 1. These data show that overall, more crashes were reported at midblock sections and at priority intersections. However, the crash rate was more than twice as high at roundabouts than at other road sections.

Table 1
Summary of route crash data by road situation (Roundabout, Priority Intersection and Midblock).

Road situation	Number of Crashes (Five years)	Number of road sections in route	Crash rate: Number of crashes per road section per year
Roundabout	24	17	0.28
Priority Intersection	39	77	0.10
Midblock	63	112	0.11

2.3. On-road drive

2.3.1. Participants

Twenty-five participants were recruited (7 male; age range 19–77; M = 47.6 years, SD = 14.8 years) through personal contacts and social media. Most participants were aged between 25 and 65 years (n = 21), with two aged less than 25 years and two aged over 65 years. Participants worked in a variety of occupations including student; technician; salesperson; communications advisor; engineer and retired. None of the participants had been involved in an injury crash during their previous five years of driving. Participant characteristics are shown in Table 2. The only selection criteria were that participants had a full New Zealand driver's licence and their own registered car to drive for the study. Participants were given a NZ$20 petrol voucher at the start of the study to thank them for volunteering to participate. The study methods were approved by the University of Waikato's School of Psychology Research and Ethics committee.

Table 2
Participant Age, Driving Characteristics and Crash History.

	Mean	SD	Range
Age (years)	47.6	14.8	19–77
Years with Full NZ Drivers' Licence	25.7	15.5	1–48
Km driven per week	220.2	308.2	30–1500
Years spent driving in Hamilton City	17.6	15.1	1–47
Number of injury crashes, previous five years	0	0	0–0
Number of non-injury crashes, previous five years	0.16	0.37	0–1

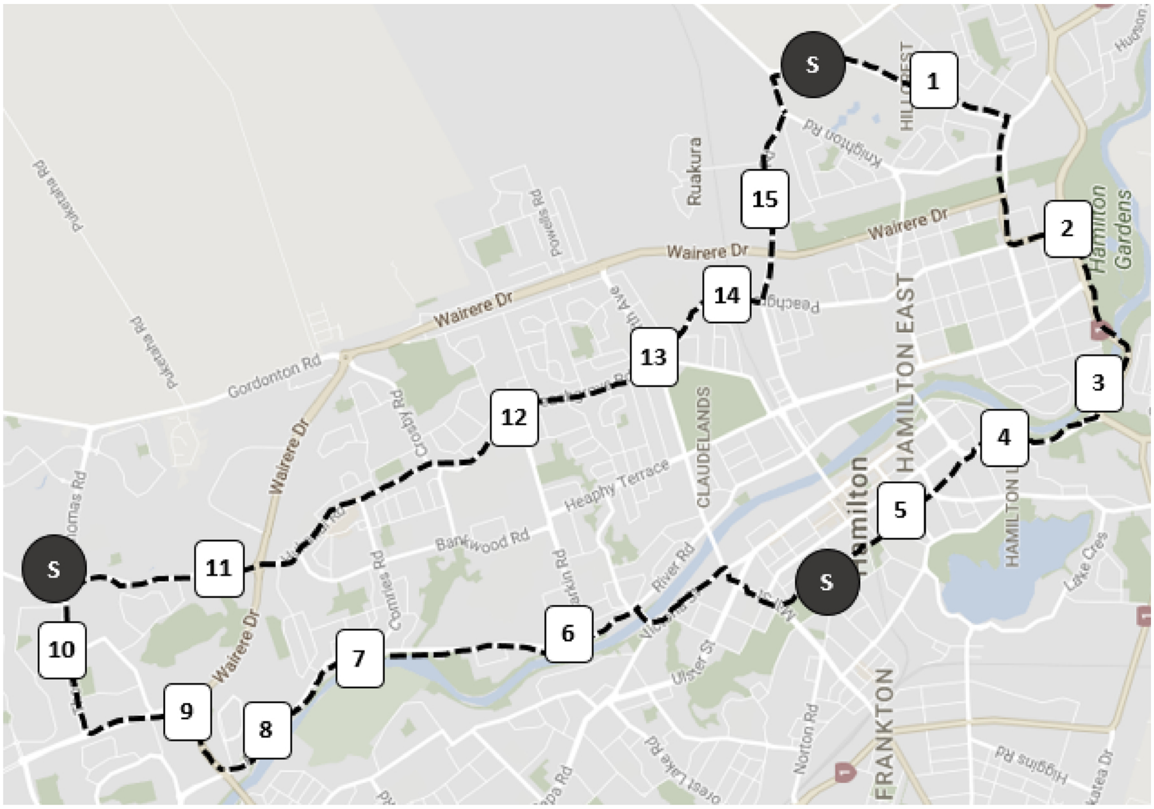

Fig. 2. Drive route, showing road sections (numbered) where drivers' thoughts were sampled, and starting points (S), which also defined the start and end of each portion of the route.

2.3.2. Drive route and thought sampling locations

Participants drove their own car, accompanied by a researcher, on the 25 km route. Participants were asked 'What are you thinking now?' at 15 preselected road sections including five roundabouts, five priority T-intersections and five midblock sections. That is, there were 15 thought sample questions for each participant and they were all asked the thought sampling question at the same places (Fig. 2). The drive was split into three portions so that participants did not need to remember too many directions at once. Each participant chose their starting point from the three shown as 'S' in Fig. 2. As well as roundabouts, priority intersections and midblock sections, each of the three portions included road sections with different posted speed limits ranging from 50 km/h to 80 km/h, and varying traffic volumes (Table 3).

2.3.3. Procedure and materials

Participants who expressed interest in the study were sent an information sheet and if they wished to participate, confirmed one of the three starting points (Fig. 2) to meet at for the study. A researcher met them at the starting point where they talked through the study procedure.

After signing a consent form, participants completed a pre-drive questionnaire. The pre-drive questions included the participant's age, address (to determine whether they lived nearby or not, as a generic indicator of route familiarity in addition to more specific ratings of familiarity provided later); and driving history (including years with a full New Zealand driver's licence; average kilometres driven per week; number of years driving in Hamilton City; and injury and non-injury crash involvement over the previous five years).

After answering the pre-drive questions, participants were shown a map with directions for the first of three portions of the drive. The route was also explained to them verbally. Participants were told that they may be asked "what are you thinking now" during the drive. Participants were not told where or how often they would be asked the thought sampling question. A researcher sat in the front passenger seat of the participant's car, to administer the questionnaires; to prompt the drivers to report what they were thinking about; and to remind participants of the route before they were required to make any turns. The drive was recorded with a camera mounted to the front passenger headrest such that it captured the view through the windscreen, as well as all audio. The recordings were used to review drivers' responses to questions and as a back-up for handwritten responses to thought sampling questions.

Participants were informed at the start of the study that they did not

Table 3
Road and traffic characteristics at thought sample road sections: Road situation, posted speed limit and traffic volume. The length of each road section was defined as 100 m (for Priority Intersections and Roundabouts); or as the actual distance between intersections (for Midblocks).

Thought Sample Road Section	Road situation: Roundabout, Priority Intersection or Midblock	Posted Speed Limit (km/h)	Traffic Volume (2016 Annual Average Daily Traffic)
1	Priority Intersection	50	4,000
2	Roundabout	80	32,000
3	Midblock	80	31,000
4	Roundabout	50	27,000
5	Midblock	50	15,000
6	Priority Intersection	50	18,000
7	Midblock	50	12,000
8	Priority Intersection	50	12,000
9	Roundabout	80	30,000
10	Midblock	50	13,000
11	Priority Intersection	50	11,000
12	Roundabout	50	21,000
13	Roundabout	50	33,000
14	Midblock	50	11,000
15	Priority Intersection	60	16,000

have to provide an answer to any question if they did not want to. Participants' responses were recorded verbatim on paper, a form of descriptive experience sampling.

After completing each portion of the 25 km route, participants were asked to pull over into a vacant parking space so that questions for the preceding portion could be asked. Participants were asked to rate the roads they had just driven on in terms of how familiar they were (on a 7-point Likert scale where 1 = completely unfamiliar/never driven on it before; to 7 = as familiar as my daily commute). Participants were free to provide different ratings for different roads within each portion with reference to a map of the route they had just driven. For each portion, participants were also asked how many times they would drive that route, or most of it, in a year; when the last time was that they drove it, or most of it; and what trip purpose was typical for them on those roads (e.g. commute; shopping trip; visiting family, etc).

Participants were given directions for the next portion, and the procedure was repeated for three portions in total until they arrived back at their starting point. At the end of the drive, as well as questions about the previous portion, participants were asked a further set of questions about the drive as a whole. They were asked to estimate what proportion of the drive they estimated that their mind was wandering, described for participants as "not thinking about driving". They were also asked how often (as a percentage) their mind wanders generally during everyday driving on familiar urban streets.

2.4. Analysis

The aim of this study was to investigate variation in both crashes and reported MW on a 25 km urban road route. The analysis was conducted in two parts, related in turn to crash data (analyses of reported crashes according to road situation: roundabout, priority intersection or midblock); and thought samples (analyses of categorised thought samples according to different road characteristics).

To explore variation in reported crashes on the route according to road situation (roundabout, priority intersection or midblock), crashes were grouped according to road situation. The numbers of crashes recorded in each of the 206 road sections were plotted by road situation in the route, with crash numbers ranging from zero to five crashes per section. Because crashes are rare, independent events, crash patterns were tested to assess whether they followed Poisson distributions using Chi-squared Goodness of Fit tests. Poisson Regression analyses were used to test the differences between the mean crash rate (number of crashes per road section), for roundabouts, priority intersections and midblock sections.

To explore variation in drivers' reported MW in different road situations, each thought sample was categorised. Thoughts were categorised as MW or driving focus, and their trigger as internal (unrelated to anything the driver could see) or sensory (something the driver saw as they drove), in line with previous taxonomies (Smallwood and Schooler, 2015; Burdett et al., 2018a). Thought triggers (sensory or internal) as well as content (MW or driving focus) were also analysed, to better understand drivers' overall sensory engagement in relation to changing task demands. Responses reflecting no particular thought at all (e.g. "not really thinking about anything") were excluded (5.9% of all thought samples). The categorisation scheme and example thought samples are shown in Table 4. Note that percentages in Table 4 sum to less than 100% because thoughts about 'nothing in particular' were excluded from further analysis.

Next, drivers' categorised thought samples were summarised to provide an overall picture of the distribution of MW and sensory engagement during the drive. To better understand where and when MW happens during everyday driving, both the content (MW vs task focus) and trigger (internal vs sensory) of drivers' thoughts were tested with three planned comparisons, namely road situation (roundabouts, priority intersections and midblocks); posted speed limit (50 km/h and > 50 km/h); and traffic volume (< 17,000 vehicles per day, and > 17,000 vehicles per day). Each planned comparison involved a one-way ANOVA.

Table 4
Categorisation of thought samples, adapted from Burdett et al. (2017a,b). Figures in brackets indicate the percentage of all thought samples in each category.

		Thought Content	
		Mind wandering	Driving focus
Thought Trigger	Internal	MW, Internal trigger, e.g. "I'm hungry" (9%)	Driving focus, Internal trigger, e.g. "Am I in the best lane" (11%)
	Sensory	MW, Sensory trigger, e.g. "Just looking at different houses along here" (38%)	Driving focus, Sensory trigger, e.g. "Driver turning left in front of me" (37%)

Finally, MW frequencies and crash rates were compared across roundabouts, priority intersections and midblocks, and for the road sections showing the highest and lowest numbers of crashes. The purpose of these comparisons was to address the main aim of the research, by comparing variation in both crashes and reported MW across different road situations on the same route.

3. Results

3.1. Crash data and regulation of attention according to crash risk

Fig. 3 shows the distribution of the number of crashes recorded in the five-year analysis period across the 206 road sections in the route, separated by road situation. There were between zero and five reported crashes reported at each road section, across the 17 roundabouts, 77 priority intersections and 112 midblock sections. The data in Fig. 3 show that over half of the road sections (114) had zero reported crashes. Overall, more crashes were reported at midblocks and priority intersections, but roundabouts were relatively more likely to show a higher number of reported crashes per road section. That is, roundabouts showed a higher crash rate than both priority intersections and midblock sections, but were the scene of fewer crashes overall because there were many more priority intersections and midblock sections on the route.

Each curve in Fig. 3 was confirmed as following Poisson distribution using a Chi-squared Goodness of Fit test (Roundabouts: $p = 0.23$; Priority intersections: $p = 0.22$; Midblocks: $p = 0.23$). Poisson regression was used to test the relationship between road situation and crash rate. Roundabouts ($M = 1.41$ crashes per section; 95% CI, 0.96–2.10) showed a significantly higher crash rate than both priority intersections

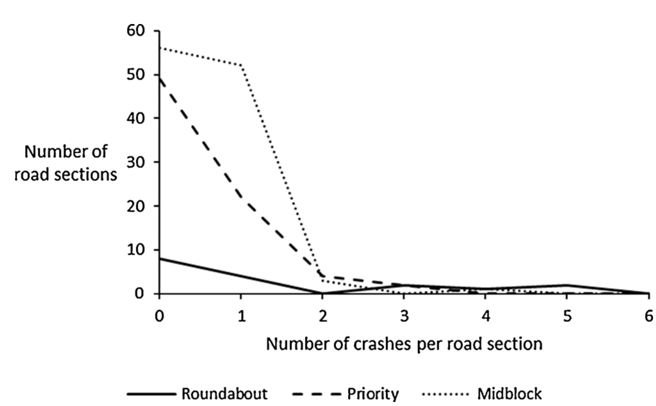

Fig. 3. Distribution of injury crashes across different types of road situation for the 25 km urban road route. Vertical axis shows the number of road sections with each crash frequency.

Table 5
Thought Samples: Descriptive Statistics (N = 25).

	Mean	SD	Range
Thought content: MW (proportion of responses to thought sampling questions categorised as MW)	0.47	0.19	0.20–0.87
Thought trigger: internal (proportion of responses to thought sampling question categorised as internally triggered)	0.22	0.17	0.00–0.53
Estimated proportion of time during this drive that mind was wandering: Participants' own estimates	0.39	0.27	0.04–0.99
Estimated proportion of time engaged in MW during everyday driving: Participants' own estimates	0.44	0.28	0.04–0.99
Mean familiarity with thought sampling question locations	5.45	0.89	3.1–0 7.0

(M = 0.47 crashes per section; 95% CI, 0.33–0.64) and midblocks (M = 0.55 crashes per section; 95% CI, 0.43–0.71; $p < 0.001$). The difference in mean crash rate between midblocks and priority intersections was not significant (p = 0.420).

3.2. Thought samples

3.2.1. Summary of MW during the drive

Descriptive statistics summarising participants' experience driving the study route, their responses to thought sampling questions during the drive and to the post-drive questionnaire are shown in Table 5. These data show that most participants were relatively familiar with the route. All participants reported MW at least once in response to thought sampling questions. When asked to estimate the proportion of time during the drive that they experienced MW, all participants estimated that their mind was wandering at least some of the time. There was no difference in reported MW based on whether or not the participant knew the researcher accompanying them ($t(24) = 0.36$, $p = 0.641$). Overall these data show that participants experienced both MW and driving task focus in relatively equal measure, across the road sections where drivers were asked to report what they were thinking about. While most thought triggers were sensory, most participants also reported internally-triggered thoughts. Participants' estimated time spent MW during the experimental drive was slightly lower on average, but similar to their estimated time spent MW during driving in everyday life

3.2.2. Thought content variation across the drive

The proportions of responses categorised as MW by road situation (roundabout, priority intersection or midblock) are shown in Fig. 4. A one-way repeated-measures ANOVA conducted on drivers' thought samples (proportions of thoughts categorised as MW) across roundabouts (M = 0.36), priority intersections (M = 0.63) and midblocks (M = 0.59) revealed a significant effect of road situation on reported MW ($F(246) = 14.75$, $p < 0.001$, $\eta_p^2 = 0.38$). Post-hoc tests with Bonferroni correction revealed significant differences in reported MW between roundabouts and priority intersections ($p_{adj.} = 0.002$) and between roundabouts and midblocks ($p_{adj.} = 0.009$). There was no significant difference in reported MW between priority intersections and midblocks ($p_{adj.} = 1.00$). MW was reported more often at midblocks and priority intersections than at roundabouts.

The proportions of responses categorised as MW by speed limit as high (> 50 km/h; M = 0.40) or low (50 km/h; M = 0.58) are shown in Fig. 4. A one-way repeated measures ANOVA conducted on drivers' thought samples across high speed and low speed road sections revealed a significant difference in terms of reported MW frequency ($F(1,23) = 9.62$, $p = 0.005$, $\eta_p^2 = 0.29$). MW was reported more often at road sections with a speed limit of 50 km/h than at road sections with a speed limit greater than 50 km/h.

The proportions of responses categorised as MW by high (> 17,000 vehicles per day; M = 0.42) or low (< 17,000 vehicles per day; M = 0.63) traffic volume are shown in Fig. 4. Drivers reported MW more often at locations with lower traffic volume than at higher volume locations ($F(1,23) = 13.98$, $p = 0.001$, $\eta_p^2 = 0.37$).

3.2.3. Thought trigger variation across the drive

The proportions of responses categorised as triggered internally by road situation (roundabout, priority intersection or midblock) are shown in Fig. 4. A one-way repeated-measures ANOVA conducted on drivers' thought samples (proportions of thoughts categorised as internally-triggered) across roundabouts (M = 0.20), priority intersections (M = 0.26) and midblocks (M = 0.20) revealed no significant effect on reported frequency of internally-triggered thought ($F(2,46) = 1.35$, $p = 0.269$, $\eta_p^2 = 0.06$).

The proportions of responses with an internal trigger, by speed limit as high (> 50 km/h; M = 0.32) or low (50 km/h; M = 0.18) are shown in Fig. 4. A one-way repeated measures ANOVA conducted on the trigger of drivers' thoughts revealed a significant difference between high speed and low speed road sections ($F(1,23) = 8.35$, $p = 0.008$, $\eta_p^2 = 0.27$). Drivers reported more internally-triggered thoughts at road sections with a speed limit of > 50 km/h than at road sections with a speed limit of 50 km/h.

The proportions of responses with an internal trigger, by traffic volume as high (> 17,000 vehicles per day; M = 0.20) or low (< 17,000 vehicles per day; M = 0.23) are also shown in Fig. 4. There was no significant difference between the proportion of internally-triggered thoughts on low volume and high volume road sections ($F(1,23) = 0.714$, $p = 0.407$, $\eta_p^2 = 0.03$).

3.3. Variation in crash rates and reported MW

To illustrate variation in both reported crash rates and reported MW on the same 25 km route, the proportion of thought samples reflecting MW was plotted alongside the mean number of crashes per road section, per situation. The data in Fig. 5 show that there is an inverse relationship between reported MW frequency as reported by a sample of drivers, and crash rates based on nationally collected data (number of reported crashes per road situation). Roundabouts showed a higher crash rate, and lowest overall frequency of reported MW. Drivers were more likely to report MW at priority intersections and midblocks, which had lower crash rates.

In terms of specific locations on the 25 km route, Table 6 shows the roundabouts, priority intersections and midblock sections with the highest and lowest reported numbers of crashes, as well as the percentage of participants reporting MW at each road section. The small samples sizes precluded statistical analyses of these data; they are provided as illustration of the association between MW and crash rate. These data show that while generally there are more crashes reported at roundabouts, which is where MW is less likely, the association is not absolute. Drivers' likelihood to report MW was relatively low at both roundabouts in Table 6, even though one of them had zero reported crashes in five years. Conversely, consistently high rates of MW were reported at midblocks and priority intersections, even though some midblock sections and priority intersections showed higher numbers of reported crashes than others. The data suggest that drivers' regulation of attention may be associated with the nature of a road situation in general, and other factors unrelated to site-specific crash risk.

4. Discussion

We set out to explore variation in crash rates and reported MW on a 25 km urban road route. We analysed crash rates across roundabouts, priority intersections and midblocks on the route. We also sampled drivers' thoughts across different road situations including across high and low speed environments, and on roads with high and low traffic volumes. We investigated how MW frequency across intersections and midblocks corresponds with the distribution of crashes across the same types of situations. Our findings provided new evidence about the

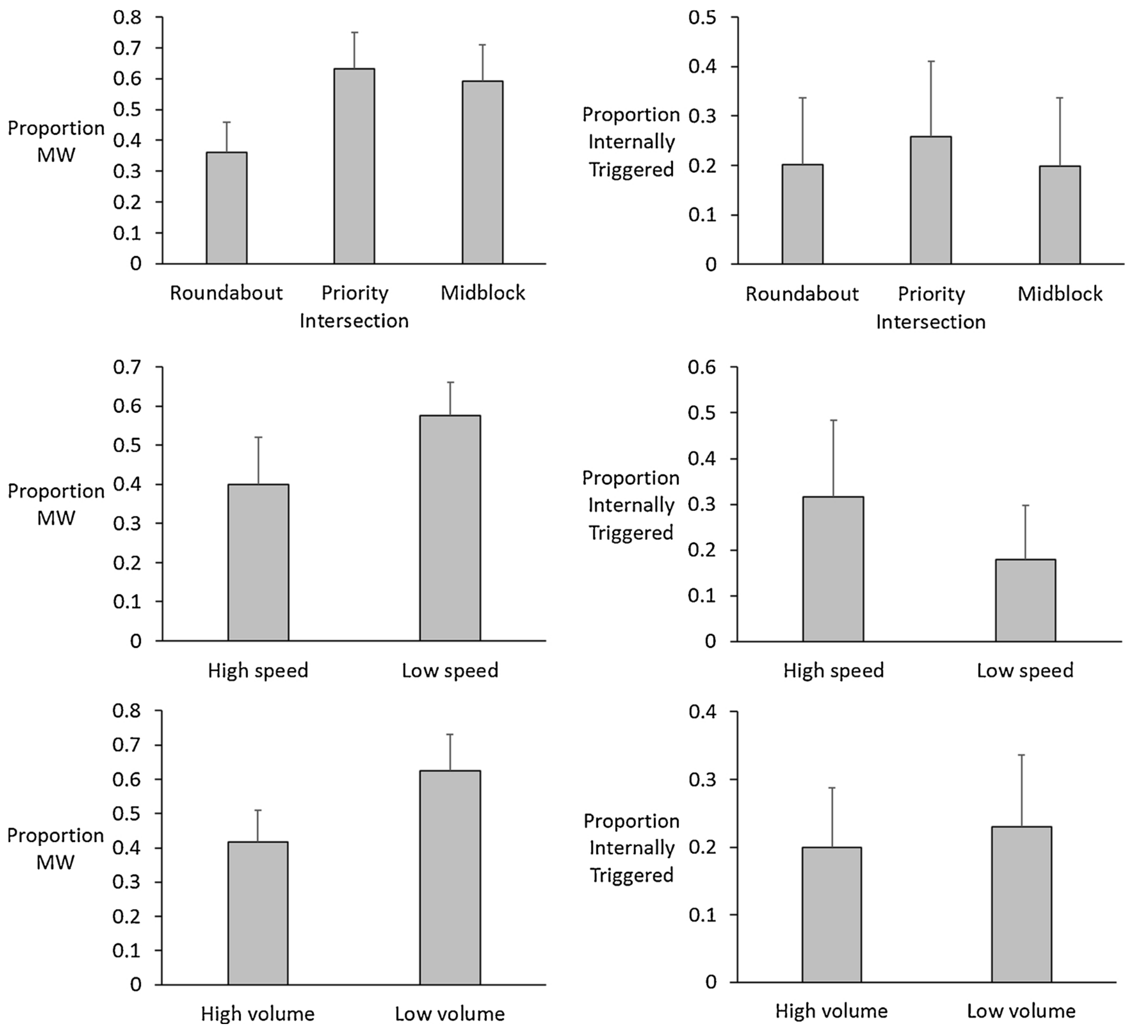

Fig. 4. Proportion of thought samples reflecting MW (left) and internally-triggered (right) thought according to road characteristics (top: location (roundabout/priority intersection/midblock); middle: high speed/low speed; bottom: high volume/low volume).

nature of MW during everyday driving and its association with crash risk.

Drivers reported MW throughout the drive, but most often at quiet, low-speed midblocks and priority intersections, which comprised most of the route. The high frequency of MW during the study supports existing evidence that MW is pervasive during everyday driving on familiar urban roads (Burdett et al., 2018a).

Even though MW was reported often, drivers maintained sensory engagement with the environment they were driving through. On average, 78% of all thought samples were triggered by something that drivers could see (or hear), including for example people on the roadside, buildings, or the weather. The proportion of thoughts that were

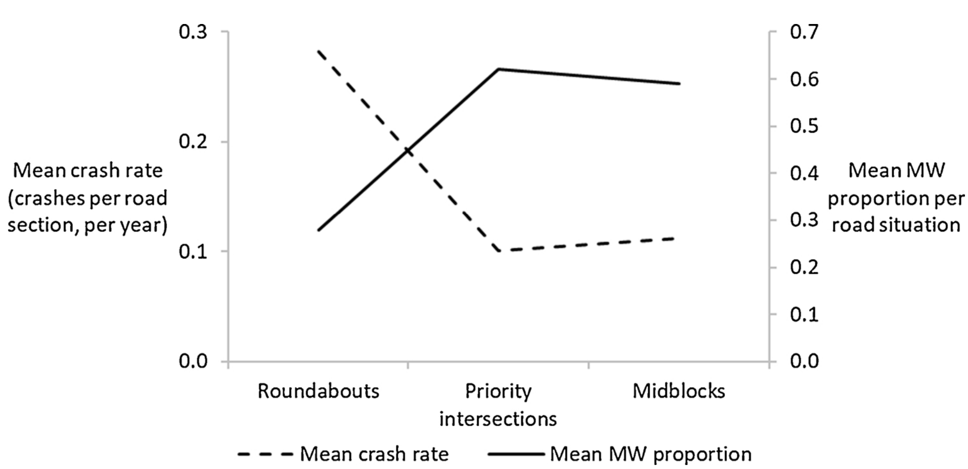

Fig. 5. Mean crash rates (reported injury crashes per road section, per year), by road situation for the 25 km route, and mean proportion of thought samples reflecting MW by road situation.

Table 6
Road sections with highest and lowest reported numbers of crashes, and MW frequency at the same road sections.

Road situation (Road section number, Fig. 1)	Number of reported injury crashes, five years 2012–2016 inclusive	Reported MW frequency (percentage of participants reporting MW)
Highest number of crashes, Roundabout (12)	3	24%
Lowest number of crashes, Roundabout (2)	0	36%
Highest number of crashes, Priority Intersection (6, 11, 15)	1	80%, 68%, 76%
Lowest number of crashes, Priority Intersection (8)	0	64%
Highest number of crashes, Midblock (3)	2	68%
Lowest number of crashes, Midblocks (10, 14)	0	72%, 48%

internally-triggered did not vary much across different road situations, or at locations with different average daily traffic volumes. When participants reported driving focus at midblocks, it was typically in response to the actions of another road user, for example "just watching this car, quite close". When there were no pertinent driving-related cues to think about, drivers' thoughts moved to what they saw and its significance in their life.

Drivers' tendency to report more internally-triggered thoughts at higher speed locations may be related to the road design at those locations. Higher-speed locations were typically dual carriageways, and many participants drove the route in off-peak times when traffic was light. The momentary situation of a wide, relatively empty road may have resulted in more drivers thinking about internally-triggered concerns because there was nothing pressing in the road environment to capture their attention.

MW varied systematically rather than randomly, and its pattern was associated with task demand and crash patterns. We found that overall, roundabouts were the most risky individual road sections, with higher crash rates than midblocks and priority intersections. Drivers were least likely to report MW at roundabouts, which were the most demanding places where we collected thought samples, because drivers were required to give way to any other traffic already circulating. More crashes were reported on the route at midblocks and priority T-intersections, but because there were so many of these sections on the route, risk at each section was low. Drivers were more likely to report MW in low risk than in high risk situations, and in situations of low rather than high demand.

To summarise our evidence from thought sampling of drivers on familiar urban roads, we found that MW was pervasive, but controlled. High proportions of thoughts triggered by what drivers saw suggest drivers scan the environment for potential driving-related cues, but most of the time driving does not command conscious focus so their minds wander. Situations of high demand and the highest crashes rates were places where MW was least likely to be reported, suggesting an inverse relationship between MW and crash risk.

Evidence concerning where and when drivers' minds wander also provides new perspectives to inform theories of MW. The results are consistent with the CRH (Smallwood and Andrews-Hanna, 2013) because MW during everyday driving appears to be regulated with respect to changing task demands. We agree that MW is a "normal rather than an exceptional state" (Smallwood and Andrews-Hanna, 2013, p1), even during a demanding task like driving. Despite the complex nature of driving, MW was not disruptive; none of our participants were involved in an injury crash in their recent driving history, or indeed, during the experimental drive. The framing of the CRH, where MW presents as a momentary interruption to task focus, was not supported by our evidence. Rather, drivers' minds wander frequently during everyday driving, where task focus is the exception rather than the rule.

Our suggestion that task focus is an exception during everyday driving does align with the tandem model of driver behaviour developed by Charlton and Starkey (2011, 2013). Indeed, our findings build on the tandem model by describing some kinds of situations that command drivers' focus, namely, high risk roundabouts and unusual or potentially risky actions of other road users.

The findings also suggest that drivers' expectations based on previous experience are involved in the switch between MW and task focus, in essence extending the tandem model. For example, we found that drivers usually focused on driving at roundabouts. Some drivers focused their attention on driving at roundabouts even when they were empty of traffic, for example "I'm thinking we're lucky there's not much traffic here today". Even when the momentary situation presents relatively low demand, the driver's expectations of roundabouts appears to dictate that it is worth their effort to pay attention. Our results comparing site-specific MW frequency and crash rates suggested that drivers may form generalised expectations for types of road features (e.g., roundabouts vs midblocks) and regulate their attention in response to the general nature of a situation rather than site-specific risk.

In terms of road safety applications, our results do not go far enough to suggest that MW causes crashes, or that task focus protects drivers from harm. All manner of factors related to the driver, other road users, the driving environment and vehicle factors affect crash risk. Crashes happen in places where drivers report more MW, and where they report less. It may be that the relatively high number of crashes at places where most MW was reported (midblocks and priority T-intersections) is related to drivers' occasional failure to correctly apply conscious focus. Therefore, road safety practitioners ought to recognise that drivers are not focused on driving for much of the time, but their attention can be readily commanded with conspicuous cues.

There are two main implications of these findings in terms of MW and road design, related to keeping drivers safe when their minds are wandering, and capturing their attention when driving task demands warrant conscious focus. Where possible, roads and roadside environments ought to be designed to align with drivers' schemas. That is, roads ought to be self-explaining, with clear links between the way the road looks and feels, and safe behaviour that is elicited without the need for drivers to apply continual conscious focus (Burdett, 2018; Charlton et al., 2010; Theeuwes and Godthelp, 1995). Transport system designers can work with the knowledge that drivers' attention can be readily commanded in situations of objectively high demand. Drivers are adept at applying conscious focus where they have learned that it is worthwhile, and we have found that links between drivers' subjective assessment of demand aligns well with objective risk at situations such as roundabouts. System designers ought to continue to research the kinds of situations that catch drivers unaware, such as places where a high proportion of MW coincides with a high crash rate. Although we found that drivers are less likely to experience MW in risky places, previous research suggests that there are gaps between subjective risk perceived by drivers, and risk assessed through analysis of crashes (Charlton et al., 2014).

These results provide new perspectives related to the way MW is viewed in the context of everyday tasks, but the study had some limitations. The sample size was relatively small and comprised mostly experienced drivers, on familiar urban streets in a relatively small city. Complexities associated with urban motorways, roadworks, periods of significant congestion, cycleways and areas with a high number of pedestrians were not explored. It is unclear how drivers might regulate their attention on journeys with a higher overall level of demand or on unfamiliar roads. The issue of attentional regulation on rural roads, for example on long cross-country journeys, uninterrupted by any requirement to negotiate intersections, remains to be investigated.

Another limitation and direction for more research lies in our conclusion that MW is an intrinsic characteristic of everyday driving and not a separable state. We used evidence based on discrete thought samples to reach our conclusion, but recognise that each thought sample represented only a snapshot of a driver's complex and swiftly changing stream of consciousness. Our results were interpreted in that context, providing a view of the broad changes in focus over the course of a drive. In doing so we advanced understanding of the way MW is experienced, beyond differences between familiar and unfamiliar situations, to variation within a familiar context. A logical next step would be to explore drivers' thoughts in yet more depth, through continued use of descriptive experience sampling, or other techniques such as protocol analysis. The aim of more research into the complexities of thoughts would be to understand more about what commands drivers' attention and what does not, so that road system designers can respond with improved infrastructure and messaging to keep all road users safe. Descriptive experience sampling could also be used to explore associations between MW and driving performance variables (such as driving speed and maintaining appropriate lane position). Driving is a complex but familiar task for many people, making everyday streets a useful testing ground for understanding more about why peoples' minds wander, building on theories of both driver behaviour and MW generally.

5. Conclusions

We conclude that MW is characteristic of drivers' thinking during everyday driving and it appears to show an inverse association with crash patterns. Drivers' minds are least likely to wander in places where crash risk is highest. In terms of the cognitive basis of MW, treating it as a separable component of cognition belies the nature of thinking during everyday life, and detracts from more pertinent issues. Research correlating MW with performance measures and concluding that it is dangerous is unhelpful, because a driver cannot prevent their mind from wandering.

We have demonstrated that everyday driving is a useful domain in which to study the nature of cognitive processes like MW, because it is such a commonly acquired skill. Furthermore, driving environments are diverse, in terms of their familiarity to individual drivers, as well as variety in the kinds of demands drivers encounter across different road sections within a route. We have also shown how analyses of crash patterns can usefully contribute understanding towards MW and its relationship with risk. Road safety practitioners can use insights into MW during driving to design environments that afford safe behaviour, given that normal driving involves frequent and somewhat predictable shifts between MW and driving focus. We have demonstrated that insights into attention and MW from analysis of well-practiced tasks such as driving can provide rich insights into the nature of everyday thinking.

References

Berthié, G., Lemercier, C., Paubel, P.V., Cour, M., Fort, A., Galéra, C., et al., 2015. The restless mind while driving: drivers' thoughts behind the wheel. Accid. Anal. Prev. 76, 159–165.

Burdett, B.R.D., 2018. Road safety policy that accounts for real everyday driving, No. 18-03988. Presented at Transportation Research Board 97th Annual Meeting.

Burdett, B.R.D., Charlton, S.G., Starkey, N.J., 2016. Not all minds wander equally: the influence of traits, states and road environment factors on self-reported MW during everyday driving. Accid. Anal. Prev. 95, 1–7.

Burdett, B.R., Charlton, S.G., Starkey, N.J., 2018a. Inside the commuting driver's wandering mind. Transp. Res. Part F: Traffic Psychol. Behav. 57, 59–74.

Burdett, B.R.D., Starkey, N.J., Charlton, S.G., 2017. The close to home effect in road crashes. Saf. Sci. 98, 1–8.

Burdett, B.R.D., Starkey, N.J., Charlton, S.G., 2018b. Characteristics of the close to home crash. Saf. Sci. 105, 222–227.

Charlton, S.G., Starkey, N.J., 2011. Driving without awareness: the effects of practice and automaticity on attention and driving. Transp. Res. Part F: Traffic Psychol. Behav. 14 (6), 456–471.

Charlton, S.G., Starkey, N.J., 2013. Driving on familiar roads: automaticity and inattention blindness. Transp. Res. Part F: Traffic Psychol. Behav. 19, 121–133.

Charlton, S.G., Mackie, H.W., Baas, P.H., Hay, K., Menezes, M., Dixon, C., 2010. Using endemic road features to create self-explaining roads and reduce vehicle speeds. Accid. Anal. Prev. 42 (6), 1989–1998.

Charlton, S.G., Starkey, N.J., Perrone, J.A., Isler, R.B., 2014. What's the risk? A comparison of actual and perceived driving risk. Transp. Res. Part F: Traffic Psychol. Behav. 25, 50–64.

Fuller, R., 2005. Towards a general theory of driver behaviour. Accid. Anal. Prev. 37 (3), 461–472.

Fuller, R., McHugh, C., Pender, S., 2008. Task difficulty and risk in the determination of driver behaviour. Revue Européenne de Psychologie Appliquée/Eur. Rev. Appl. Psychol. 58 (1), 13–21.

Galéra, C., Orriols, L., M'Bailara, K., Laborey, M., Contrand, B., Ribéreau-Gayon, R., et al., 2012. Mind wandering and driving: responsibility case-control study. BMJ 345, e8105.

Handy, S., Weston, L., Mokhtarian, P.L., 2005. Driving by choice or necessity? Transp. Res. Part A: Policy Pract. 39 (2), 183–203.

Harms, I.M., Brookhuis, K.A., 2016. Dynamic traffic management on a familiar road: failing to detect changes in variable speed limits. Transp. Res. Part F: Traffic Psychol. Behav. 38, 37–46.

He, J., Becic, E., Lee, Y.C., McCarley, J.S., 2011. Mind wandering behind the wheel: performance and oculomotor correlates. Hum. Fact. 53 (1), 13–21.

Kane, M.J., Gross, G.M., Chun, C.A., Smeekens, B.A., Meier, M.E., Silvia, P.J., Kwapil, T.R., 2017. For whom the mind wanders, and when, varies across laboratory and daily-life settings. Psychol. Sci. 28 (9), 1271–1289.

Killingsworth, M.A., Gilbert, D.T., 2010. A wandering mind is an unhappy mind. Science 330 (6006), 932.

Lewis-Evans, B., Rothengatter, T., 2009. Task difficulty, risk, effort and comfort in a simulated driving task—implications for risk allostasis theory. Accid. Anal. Prev. 41 (5), 1053–1063.

Mooneyham, B.W., Schooler, J.W., 2013. The costs and benefits of mind-wandering: a review. Can. J. Exp. Psychol. Can. Psychol./Revue canadienne de psychologie expérimentale 67 (1) 11.st.

NZ Transport Agency, 2017. Crash Analysis System. Wellington: New Zealand.

Papp, K.K., Stoller, E.P., Sage, P., Aikens, J.E., Owens, J., Avidan, A., et al., 2004. The effects of sleep loss and fatigue on resident–physicians: a multi-institutional, mixed-method study. Acad. Med. 79 (5), 394–406.

Smallwood, J., Andrews-Hanna, J., 2013. Not all minds that wander are lost: the importance of a balanced perspective on the mind-wandering state. Front. Psychol. 4, 441.

Smallwood, J., Schooler, J.W., 2006. The restless mind. Psychol. Bull. 132 (6), 946.

Smallwood, J., Schooler, J.W., 2015. The science of mind wandering: empirically navigating the stream of consciousness. Annu. Rev. Psychol. 66, 487–518.

Song, X., Wang, X., 2012. MW in Chinese daily lives–an experience sampling study. PLoS One 7 (9), e44423.

Spronken, M., Holland, R.W., Figner, B., Dijksterhuis, A., 2016. Temporal focus, temporal distance, and mind-wandering valence: results from an experience sampling and an experimental study. Conscious. Cogn. 41, 104–118.

Steinberger, F., Moeller, A., Schroeter, R., 2016. The antecedents, experience, and coping strategies of driver boredom in young adult males. J. Saf. Res. 59, 69–82.

Theeuwes, J., Godthelp, H., 1995. Self-explaining roads. Saf. Sci. 19 (2–3), 217–225.

Wilde, G.J., 1982. The theory of risk homeostasis: implications for safety and health. Risk Anal. 2 (4), 209–225.

Wilde, G.J., 1998. Risk homeostasis theory: an overview. Inj. Prev. 4 (2), 89–91.

Yanko, M.R., Spalek, T.M., 2013. Driving with the wandering mind: the effect that mind-wandering has on driving performance. Hum. Fact. 56 (2), 260–269.