# Prevalence and self-regulation of drivers' secondary task engagement at intersections: An evaluation using naturalistic driving data

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**Abstract: On the basis of naturalistic driving data, this study examined the prevalence of secondary task engagement at intersections and investigated how drivers self-regulate and manage such activities in accordance with changing roadways and demand situations. Video recordings were viewed to identify secondary tasks in which drivers engaged and situational factors, specifically those related to the complexity of driving situations. Results showed that one-third of the total intersection time was allocated to secondary task engagement and that greater engagement occurred at upstream and downstream areas of intersections than at areas falling within intersections. Drivers tended to more frequently engage in secondary tasks when their vehicles were stationary than when the vehicles were moving. Elderly drivers were less likely to engage in secondary tasks than younger drivers. Finally, drivers were less likely to engage in secondary tasks when they did not have priority than when they had priority and at intersections managed through traffic signs than in those controlled by traffic lights. In conclusion, drivers appear to engage selectively in secondary tasks at intersections in accordance with changes in the demands imposed by driving and roadway situations. In such circumstances, drivers likely respond to increased demand and reduce secondary task engagement to preserve processing resources. The findings offer the preliminary information necessary to develop driver training/education and awareness programmes on managing distractions and safe driving strategies.**

## 1. Introduction

Driving is regarded as a complex multitasking activity that necessitates the simultaneous execution of several physical, cognitive and sensory skills. Despite such complexity, however, drivers commonly occupy themselves concurrently with distracting activities (secondary tasks) whilst driving [1]. Driver distraction can be defined as the diversion of attention away from safety-critical driving activities towards a competing activity, which may lead to insufficient or no attention being given to activities critical for safe driving [2]. Driver distraction is widely classified as a significant contributor to road crashes and a major concern for traffic safety [3-8].

Driving behaviours in the real world are illuminated using observational studies called Naturalistic Driving Studies (NDS), wherein data are collected through unobtrusive equipment that is installed in a vehicle, with no experimental intervention applied [9]. Previous NDSs provided sophisticated insights into the mechanisms that underlie the driver distraction-related process. An example is the Strategic Highway Research Program 2 project, which showed that drivers who engage in secondary tasks are exposed to double the risk of crashing than that presented to attentive drivers [3]. Notwithstanding the value provided by such initiatives, evaluating the crash risk arising from the performance of secondary activities without considering how drivers manage or self-regulate secondary task engagement does not unravel the entirety of the complexity that characterises safe driving.

The management of secondary task engagement encompasses decisions on when to engage in secondary activities, what types of activities to engage in and whether adjustment is to be made in accordance with variations in the demands imposed by the primary driving task [10]. Management can take place when drivers forgo secondary task engagement altogether whilst driving or when they refrain from engaging in specific secondary tasks under certain demanding situations. Acquiring a better understanding of secondary task management can improve estimations of crash risk and advance comprehension of the safety effects of driver distraction [11].

Many studies have implemented the naturalistic driving (ND) approach to illustrate how drivers manage their engagement in secondary tasks. An early study conducted in the US, for instance, revealed that drivers tend to less frequently occupy themselves with secondary tasks when they are driving at night, braking, driving on wet roadways and travelling through horizontal curves [12]. Other studies found that drivers are more likely to engage in secondary tasks when their vehicles are stationary than when they are moving [13-15]. In a similar study carried out in the Swedish context, the researchers concluded that drivers are less likely to initiate visual–manual secondary tasks during high-driving-demand situations (e.g. sharp turns and high speeds) and that drivers wait until they have completed lane changing manoeuvres before initiating secondary tasks [16]. These findings suggest that drivers self-regulate their behaviours by selecting what they evaluate as safe periods at which to engage in secondary tasks. A deficiency in this regard is the lack of studies that deal with drivers' self-regulation at intersections.

Focusing on intersections as one of the most safety-critical and highly demanding locations within a road network is a relevant component of enquiries into self-regulation behaviours because intersection negotiation poses extra demands on a driver and features heavily in crash statistics. For instance, intersection-related crashes represent nearly 50% of the total number of injury crashes in Germany [17] and nearly 60% of that in the UK [18]. Despite the fact that intersections are prominently implicated in crashes, there is a limited understanding of real-world driving behaviours at these locations. In particular, relatively little is known about the willingness of drivers to engage in secondary tasks and the manner by which they manage such engagement in accordance with changing demand situations at these sites.

The core idea that underpins this study is the in-depth analysis of drivers' engagement in secondary activities whilst performing manoeuvres at intersections. The analysis was based on ND data from the large-scale European naturalistic driving project known as the 'eUropean naturalistic Driving and Riding for Infrastructure & Vehicle safety and Environment' (UDRIVE). The importance of the current study lies in the combination of two key critical challenges to road safety: distractions and intersection. Correspondingly, the investigation was aimed at probing into the types of secondary tasks (e.g. mobile phone use, smoking, eating) that drivers typically engage in as they pass through intersections and exploring the prevalence of such conduct. The study was also intended to ascertain whether engagement in secondary tasks at intersections is influenced by driver-related personal characteristics, such as age and gender, and some situational variables, specifically those related to complex aspects of driving situations, including intersection control measures (traffic lights or traffic signs and road markings), intersection priority and vehicle status (moving or stationary). Finally, the study was directed towards a distraction-related comparison of the intersection approach phase (upstream functional area), the during-intersection phase (intersection physical area) and the beyond-intersection phase (downstream functional area) to explore how drivers manage secondary task engagement at intersections in accordance with changing roadways and demand situations.

## 2. Methods

To look into whether drivers adjust their secondary task engagement whilst driving at intersections, ND data from the UDRIVE project were coded and analysed. The observational data were supplemented by some driver-related factors (e.g. age and gender) which were obtained through questionnaires administered to participants in the recruitment stage. This study was approved by the Research Ethics Committee of the Environment Faculty at the University of Leeds (Ethics reference: AREA 16-193).

### 2.1. Participants

The sample comprised 163 car drivers (78 females and 85 males) who had more than 20 trips recorded in the UDRIVE dataset. Their age ranged from 18 to 80 years [mean = 43.8, standard deviation (SD) = 13.1] (Table 1), and their geographical locations were distributed across five European countries (the UK, France, the Netherlands, Germany and Poland).

**Table 1.** Descriptive statistics of age groups (in years)

| Age | N | Mean | Minimum | Maximum | SD |
|---|---|---|---|---|---|
| 18-29 | 19 | 24.7 | 18 | 28 | 3.2 |
| 30-39 | 52 | 34.6 | 30 | 39 | 3.0 |
| 40-59 | 66 | 48.0 | 40 | 58 | 5.6 |
| 60-80 | 26 | 65.3 | 60 | 80 | 5.7 |
| Total | 163 | 43.8 | 18 | 80 | 13.1 |

### 2.2. UDRIVE data acquisition system

The participants' own vehicles were equipped with a data acquisition system (DAS), which remained in the vehicles for 18 months from mid-2015 to early 2017. The DAS is composed of (1) a combination of sensors that automatically provide continuous measurements (e.g. an accelerometer, a global positioning system and an internal controller area network intended to measure speed, brake pedalling, engine revolutions per minute, etc.); (2) a smart forward-facing camera that detects and measures frontward distances from other road users; and (3) multiple other cameras for broad video coverage of road environments and driver behaviours (eight cameras in total) [19].

The cameras provide images of a driver's forward and side views and in-cabin views, with minimal disturbance to the driver's line of sight. These cameras are (1–3) three front cameras (left, centre, right) that capture approximately 180° views of a vehicle's front situation; (4) a face camera that captures a driver's facial expressions and gaze directions; (5) a blind spot camera that captures possible road users on the right side of a vehicle; (6) a driver action camera positioned over the shoulders to record the actions of a driver's hands; (7) a cabin camera that records the presence and activity of passengers; and (8) a foot camera that captures the actions of a driver's feet [20]. The participants could deactivate the recording system of the cameras by pressing a button assigned for this purpose [21]. This was considered a very important requirement for satisfying ethics standards and enabled the drivers to terminate recording temporarily for any reason as they drove.

### 2.3. Data sampling

The UDRIVE project yielded data on nearly 140,000 trips, with nearly 46,000 hours of ND data and nearly 1.5 million intersection cases. A robust sampling process was established for the selection of a representative sample of the UDRIVE dataset. The criteria used for sampling the intersection cases were as follows:

- A driver should have made at least 20 trips, with a minimum distance of 1 km per trip.
- For each driver, 10 trips were sampled randomly without replacement.
- For each trip, one intersection case was sampled randomly across all the intersection cases within that trip. Each intersection case was selected from a unique trip (no more than one intersection case selected per trip).
- For the annotated intersection cases, certain conditions had to be satisfied. That is, all camera channels should have been properly oriented and sufficient for annotation. Continuous measurements by sensors should have been existing and perfectly synchronised with the camera channels.

The above-mentioned selection process produced a sample of 163 drivers with 1630 intersection cases (10 intersection cases per driver).

### 2.4. Data coding and analysis

A scheme developed specifically for this study was used to code the selected sample to appropriately define different categories related to secondary activities, drivers' personal characteristics (age and gender) and situational factors. The key variables are described as follows:

Secondary tasks: The main dependent variable was the proportion of total intersection time accounted for by secondary tasks. Drawing from key distraction studies [10, 15, 22], the present research identified 10 secondary task types for annotation: passenger conversations (i.e. any instance of conversation, whether as minimal as a single-word utterance, with a passenger in an observed segment), talking/singing with no passengers present, mobile phone-related tasks, interactions with in-vehicle control systems (e.g. adjusting climate control), smoking-associated activities, grooming-related tasks, eating/drinking-related tasks, reading/writing-related activities, electronic device-related tasks and navigation system-related tasks (coded when a map can be observed from video channels or when some kind of interaction with a map transpires). A secondary task activity was annotated in a separate channel wherein multiple tasks could be coded simultaneously (e.g. a driver talking on a mobile phone whilst manipulating an in-vehicle control system).

*Drivers' age categories*: In line with the UDRIVE risk factors, crash causation and everyday driving reports [23], driver age was classified into four ordinal age groups: 18 to 29 years, 30 to 39 years, 40 to 59 years and 60 to 80 years.

Intersection type: Intersections were coded as roundabouts or intersections.

Intersection control: Intersection control measures were coded as control via traffic lights or management through traffic signs and road markings.

Intersection priority: Intersections were coded on the basis of priority as intersections in which a subject vehicle (SV) has priority or intersections in which an SV has no priority.

Turning direction: Three categories of turns were studied, namely, right turns, left turns and going straight through an intersection. A noteworthy point here is that the UK is the only country within the UDRIVE project where people drive on the left side of a road. Accordingly, descriptions of turning directions in the UK were flipped to match the data on the other countries.

Intersection locality: Intersection approaches were coded as located in urban or rural areas.

Vehicle motion status: The motion status of vehicles was coded as 'stationary' or 'moving' on the basis of time-series speed data. A stationary condition was defined as a situation wherein vehicle speed drops to zero (full stop). Earlier studies [e.g. 15] expected drivers to realise that the driving task is less demanding when vehicles are stationary and accordingly adapt secondary task engagement.

Given that the study was aimed at comparing secondary task engagement in the intersection upstream, intersection physical and intersection downstream areas, an essential requirement was to employ a mechanism that delineates the boundaries of these phases. The intersection functional area can be defined as a distance-based zone that extends both upstream and downstream beyond the boundaries of the intersection physical area [24]. The major component considered in determining this distance-based zone is the stopping sight distance (SSD). The SSD, in turn, is primarily based on speed and can be derived by adding the distance travelled during perception–reaction time to the distance travelled whilst braking [25–27].

The current work adopted the physical length values of the intersection functional area that were published in two previous studies (one step below the desirable minimum values) [24, 27]. These distance-based zone values were varied in accordance with the speed limit at intersections, as shown in Table 2.

**Table 2.** The physical length of the intersection functional area as a function of speed at intersections

| Speed (km/h) | Physical length (m) |
|---|---|
| 30 | 25 |
| 40 | 35 |
| 50 | 50 |
| 60 | 70 |
| 70 | 90 |
| 80 | 115 |
| 90 | 140 |
| 100 | 160 |

A UDRIVE-developed visualisation tool called SALSA (Smart Application for Large Scale Analysis) was used as the viewing platform to facilitate the viewing and annotation of the data. The reliability of the coded data was tested via inter-rater checks, for which a second independent coder coded 10% of the intersection cases. Inter-rater reliability was nearly 95% for the categorical variables (e.g. intersection priority) and nearly 90% for the continuous variables (e.g. secondary task duration).

The Statistical Package for the Social Sciences version 24 was used for the data analysis. Several descriptive and inferential analyses were carried out to examine the types and prevalence of secondary task engagement in relation to the selected situational and personal driver variables. The primary metric selected to evaluate the prevalence of secondary task engagement was the proportion of total intersection time accounted for by secondary tasks. Other metrics were the proportion of upstream intersection time, during-intersection time, downstream intersection time, total moving time and total stationary time accounted for by secondary tasks. The aforementioned variables were non-normally distributed; hence, non-parametric statistical tests were performed, namely, the Mann–Whitney U test, the Kruskal–Wallis H test, the Wilcoxon signed-rank test and the Friedman test.

## 3. Findings and discussion

The analysis was directed towards 1630 intersection cases, amounting to a total of 678.8 min of observation time. The mean duration of an intersection segment was 25 s. In term of motion status, the total 678.8 minutes observation time divided into 536 minutes of moving time and 142.8 minutes of stationary time. In term of the intersection stages, the total 678.8 minutes observation time divided into 373.2 minutes for upstream-, 161.2 minutes for during- and 144.4 minutes for downstream-stage.

With respect to the situational factors, the 1630 intersection cases were assigned to categories according to each situational variable in Table 3.

**Table 3.** Situational factors obtained from data coding

| Situational factor | % of total intersection cases (1630 cases) |
|---|---|
| **Intersection type** | |
| Intersections | 74.0 |
| Roundabouts | 26.0 |
| **Intersection control** | |
| Traffic lights | 37.1 |
| Traffic signs and road markings | 62.9 |
| **Intersection priority** | |
| SV has priority | 50.5 |
| SV has no priority | 49.5 |
| **Intersection locality** | |
| Urban | 75.3 |
| Rural | 24.7 |
| **Turning direction** | |
| Turning right | 32.5 |
| Turning left | 30.1 |
| Going straight | 37.4 |

### 3.1. Overall results on secondary task engagement

The analysis revealed that 50.9% of the intersection cases and 30.6% of the total intersection time involved engagement in at least one kind of secondary task. In other words, nearly one-half of the intersection cases and one-third of the total intersection time involved engagement in secondary tasks. Amongst all the cases, 555 (34.1%) were characterised by driver engagement in a single secondary task, 221 (13.6%) featured driver engagement in two secondary tasks and 53 (3.2%) involved driver engagement in more than two secondary tasks.

The UDRIVE project indicated that 52% of the coded trips and 10.2% of the analysed total travel time involved at least one secondary task [10]. By contrast, the current work discovered a higher level of secondary task engagement. This difference is likely due to coverage—the UDRIVE analysis was performed across the full range of driving contexts, whereas the present analysis was restricted to intersections. Moreover, the current study included two types of secondary tasks that were not covered in the UDRIVE project: passenger conversations and activities related to embedded/integrated in-vehicle navigation systems.

### 3.2. Frequency and prevalence of secondary tasks engagement

Table 4 presents the frequency at which the drivers performed each secondary task type at intersections. Overall, the data revealed that the most frequently observed tasks were passenger conversations (n = 456) and talking/singing in the absence of passengers (n = 148), followed by mobile phone interactions (n = 132), navigation system interactions (n = 109) and in-vehicle control system-related tasks (n = 99). Reading and writing tasks accounted for the lowest frequency (n = 6). These findings are consistent with previous NDSs in which passenger conversations were the leading secondary tasks observed [3, 15].

**Table 4.** Frequency of secondary tasks

| Secondary task | Frequency |
|---|---|
| Passenger conversations | 456 |
| Talking/Singing with no passengers present | 148 |
| Mobile phone-related tasks | 132 |
| Navigation system-related tasks | 109 |
| Interactions with in-vehicle control systems | 99 |
| Smoking-related tasks | 74 |
| Personal grooming-related tasks | 74 |
| Food- and drink-related tasks | 29 |
| Reading- and writing-related tasks | 6 |
| Other | 30 |
| Total | 1157 |

In the UDRIVE project, mobile phone usage and talking/singing tasks were the most frequent, whereas reading/writing was the lowest-frequency task [10], consistent with the findings of the current study (accounting for the absence of passenger conversation tasks). The only difference between the two studies is the relative frequency of personal grooming and food/drink-related tasks; that is, these behaviours occurred less frequently in the present study. This disparity may be attributed to the specificity of the driving manoeuvres executed in the intersections cases and may therefore suggest a form of self-regulatory practice by drivers. This self-regulation is that drivers ban or reduce their engagement in certain secondary tasks at intersections.

As a second step in analysing type of task engagement, the total amount of time that the drivers allocated to each secondary task was compared with the total intersection time (678.8 min). Figure 1 indicates that passenger conversations were the most frequently performed tasks, as determined from the proportion of these tasks out of the total intersection time (13.2%), followed by mobile usage (6.6%), navigation system-related tasks (6.6%) and smoking-related tasks (3.7%). The finding on passenger conversations accounting for the highest proportion of secondary task engagement is consistent with an early NDS in which passenger conversation was the leading secondary task, as determined on the basis of the proportion of time allocated to this task out of the total driving time (15.3%) [15]. Another NDS consistent with the current research showed that passenger conversations and mobile phone-related tasks accounted for 14.6% and 6.4% of the total baseline duration, respectively [3]. The results of the present study are also consistent with the findings on the UDRIVE general driving context, albeit this interpretation does not consider passenger conversations and navigation system-related tasks [10].

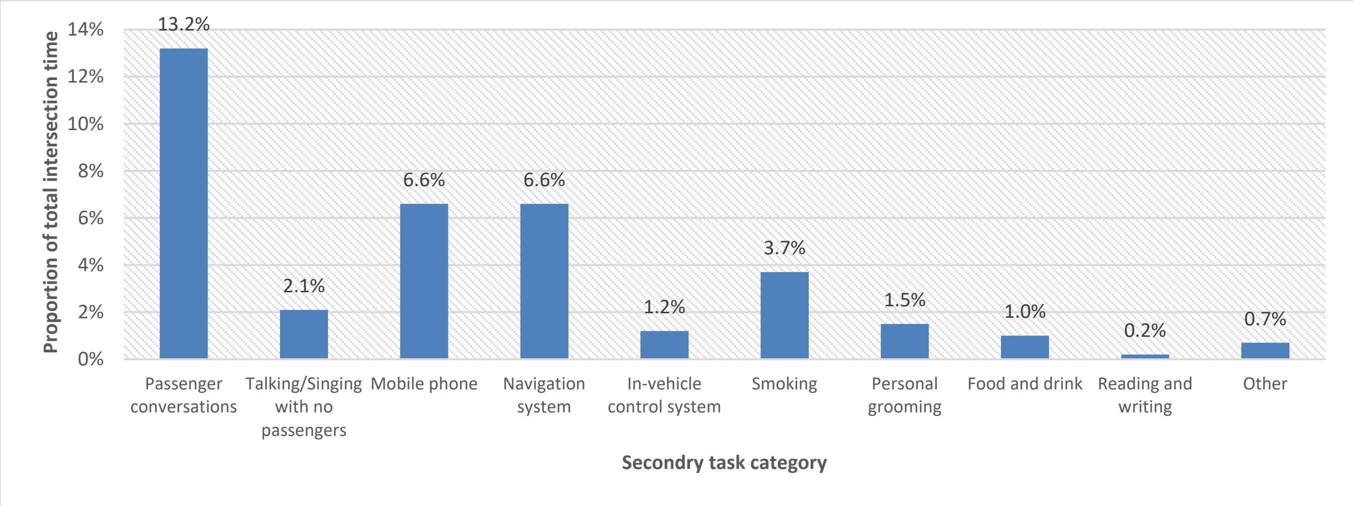


**Figure 1.** Proportions out of total intersection time by type of secondary task

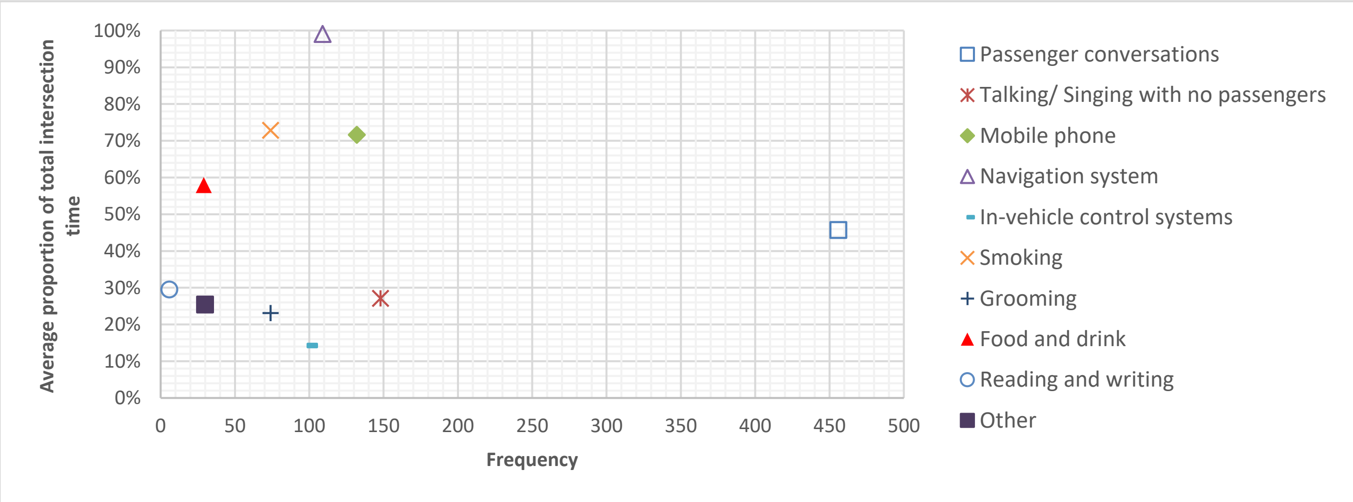


**Figure 2.** Secondary task frequency versus average proportion of intersection time allocated to each task type

The third step in delving into type of task engagement was determining the relationship between each task's frequency and average proportion accounted for in the total intersection time (Figure 2). Navigation system-related tasks were the activities to which the longest average proportion of time (99.1%) was devoted, which was an expected result given that such activities were coded for as long as a screen could be seen and independently from the modality of the interactions. Conversely, interactions with in-vehicle control systems were accorded the shortest average proportion of time (14.3%), which was also expected because of the short duration required to perform these tasks. Passenger conversations were devoted an average proportion of 45.7% but were by far the tasks with which the drivers most frequently occupied themselves. Mobile phone usage and smoking-associated tasks had similar average proportions, but the former was a more frequently exercised activity. Only six reading/writing tasks were observed within the annotated data, with these activities receiving an average proportion of 29.5% out of the total intersection time.

### 3.3. Proportions of time allocated to secondary tasks at each intersection stage and motion status

As mentioned earlier, 30.6% of the total intersection time was associated with secondary task engagement. Figure 3 shows a breakdown of the proportions of total intersection time by intersection stage (upstream, during and downstream) and by vehicle motion status (moving and stationary).

The Friedman test results showed that the proportions of time accounted for by secondary task engagement significantly differed at different intersection stages, $\chi 2(2) = 76.364$, $p < 0.0005$. Pairwise comparisons indicated significantly higher engagement during the upstream and downstream stages than at the during intersection stage. These results suggest that drivers reduce secondary task engagement in the during-intersection stage as a self-regulatory measure. Drivers likely respond to increased risk/demand when they are located at the physical intersection area and reduce secondary task engagement to preserve processing resources. These outcomes constitute what can be called a V-shaped relationship between secondary task engagement and the three intersection stages (Figure 3).

The Wilcoxon signed-rank test revealed that the drivers significantly increased the proportion of time devoted to secondary tasks when their vehicles were stationary compared with when their vehicles were moving, z = –7.196, p < 0.0005. Again, the drivers appeared to self-regulate at intersections, indicating that they are more likely to perform secondary tasks when driving task demand is lower at stationary conditions (Figure 3). This increment in engagement, however, does not mean that it is a safe practice. In these situations, drivers will be compelled to generate extra cognitive load, which in turn, may slow down driver decision making.

### 3.4. Proportions of time allocated to secondary task engagement as determined by stationarity

Figure 4 illustrates the comparison of secondary task engagement at intersections with (436 cases) and without (1194 cases) stationarity. For both conditions, the Friedman test showed a significant difference in the proportions of time accounted for by secondary task engagement across the intersection stages. Moreover, the V-shaped relationship between secondary task engagement and intersection stage remained under the two scenarios (Figure 4).

Post-hoc pair-wise comparisons of the cases wherein no stationarity occurred revealed statistically significant increases in task proportions from the during-intersection to the downstream intersection stages (p = 0.014). In regard to the stationarity cases, the proportion of secondary task engagement was significantly higher in the upstream stage than in the during-intersection and downstream stages (p < 0.0005). These results suggest that drivers who pass through an intersection without stopping are more likely to wait until exit from the during-intersection stage before initiating secondary tasks. Those who stop, however, tend to allocate time to task engagement in the upstream stage and then abandon the activity to keep pace with the increasing demand encountered at the during-intersection stage. These results imply that stationarity significantly affects drivers' decisions regarding when to engage in secondary tasks across the intersection stages. Stationarity-induced engagement can thus be considered another form of self-regulatory practice.

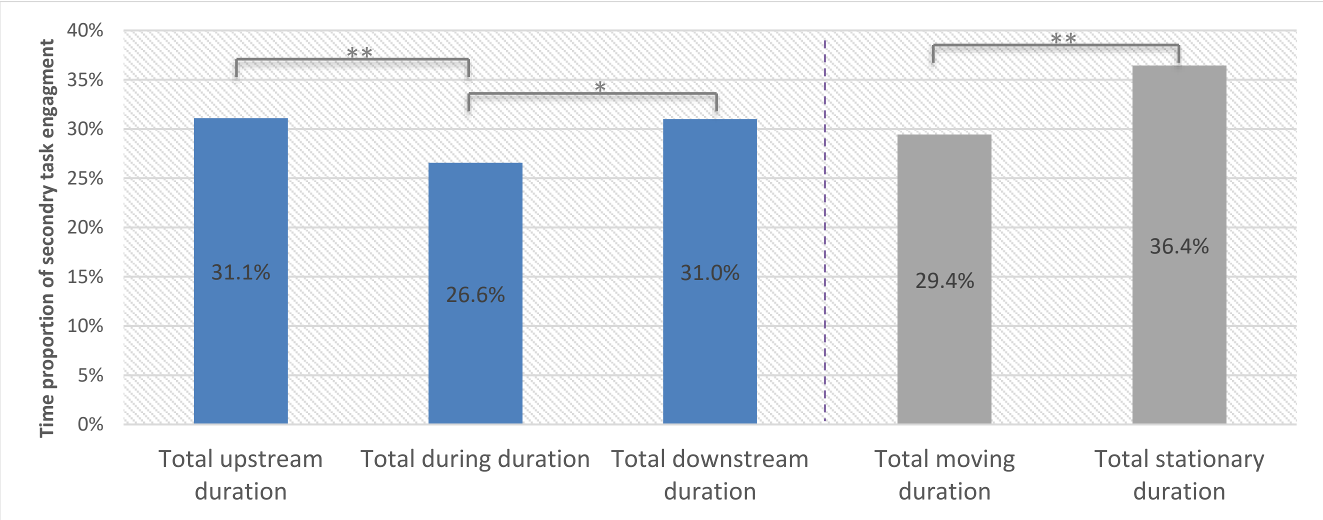


**Figure 3.** Proportions of time allocated to secondary task engagement at each intersection stage and motion status (*p < 0.05, **p < 0.0005)

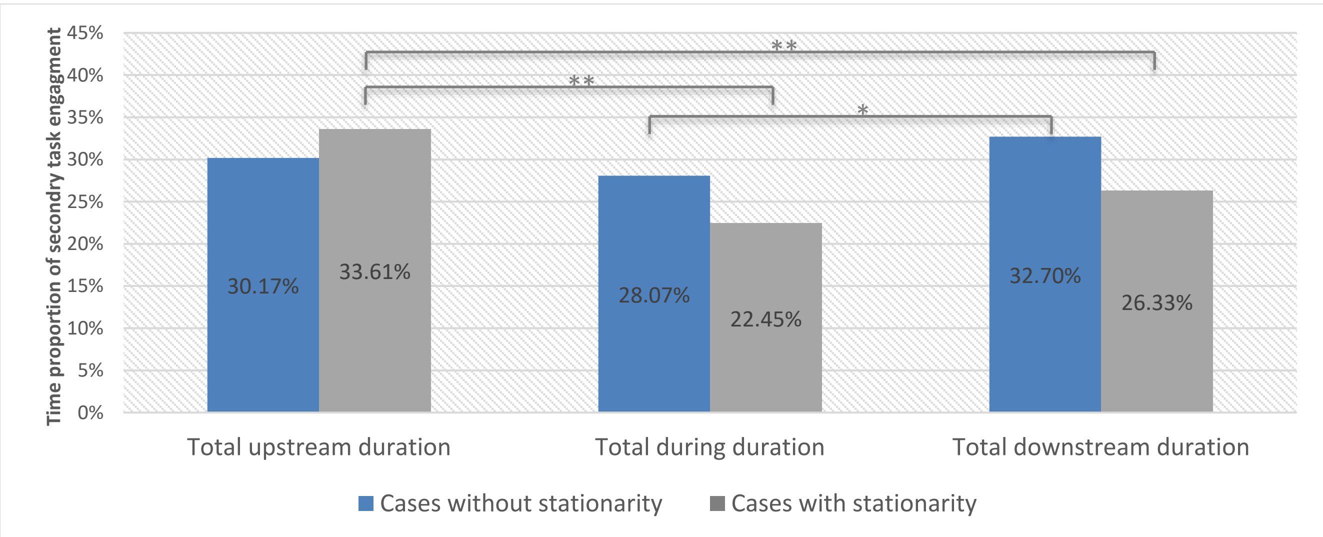


**Figure 4.** Proportions of time allocated to secondary task engagement at each stage by presence of stationarity (*p < 0.05, **p < 0.0005)

### 3.5. Secondary task engagement based on driver-related factors

The Mann–Whitney U and Kruskal–Wallis H tests were conducted to determine whether significant differences exist between the two genders and amongst the four age groups, respectively, in terms of the proportion of time allocated to secondary tasks. The time proportions tested here were those pertaining to the total intersection time, as well as the time proportions allocated to each intersection stage and motion status.

The data analysis revealed that gender did not exert a significant effect on the proportions of time that the drivers allocated to secondary task engagement (Table 5). This result is consistent with that of an Australian NDS, which reported no significant difference in task engagement allocations between males and females [14]. With respect to age, the analysis unravelled a significant difference in the proportions of time allocated to secondary task engagement amongst the age groups (Table 5). Proportion decreased with age under all the intersection stages and motion statuses. Figure 5 shows how the relationship between the proportion out of total intersection time and age group was shaped. The result indicates that elderly drivers are less likely to engage in secondary activities than younger ones—a finding that aligns with many studies within the driving literature [e.g. 15, 28]. A plausible conclusion, then, is that this behavioural trend is sustained, especially when one considers the complexity of driving at intersections and the reduced abilities of elderly drivers (e.g. sensory, cognitive and physical functioning).

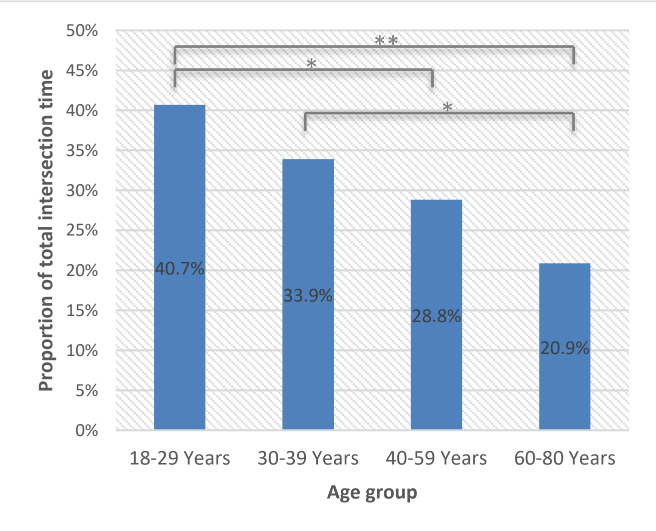


**Figure 5.** Proportion of total intersection time allocated to secondary tasks by age group (*p < 0.05, **p < 0.0005)

### 3.6. Secondary task engagement based on situational factors

The Mann–Whitney U test was used to determine whether significant differences exist amongst intersection type, intersection control, intersection priority and intersection locality with respect to the proportions of time allocated to secondary tasks. The Kruskal–Wallis H was carried out to determine whether significant differences exist amongst the three categories of turning directions in terms of the aforementioned proportions.

With regard to intersection control, the proportions of time out of the total intersection time ($z = -3.022$, $p = 0.003$), the total upstream time ($z = -4.498$, $p < 0.0005$) and the total stationary time ($z = -2.488$, $p = 0.013$) during which the drivers engaged in secondary tasks were lower at intersections with traffic signs than at intersections with traffic lights (Table 6). This result suggests that drivers self-regulate secondary task engagement by reducing interactions at intersections that are managed by traffic signs (which require gap judgments) to levels below engagement at intersections that are fully controlled by traffic lights.

With reference to intersection priority, the proportions of time in which the drivers were occupied with secondary tasks were significantly higher in situations wherein the drivers had priority, but this applied only with respect to total stationary time ($z = -3.005$, $p = 0.003$) (Table 6). This result suggests that drivers, whilst stationary condition at intersection approaches, are more likely to engage in secondary tasks when they have priority than when no such priority is accorded to them. This supposition is reasonable because drivers are required to judge gaps and choose the best option for crossing an intersection (high decision-making demand) as they stop at non-priority locations. Drivers therefore self-regulate secondary task engagement in these situations.

In terms of intersection type, the proportions of time out of the during time ($z = -2.110$, $p = 0.035$), the downstream time ($z = -2.241$, $p = 0.025$) and the total moving time ($z = -2.332$, $p = 0.020$) during which the drivers occupied themselves with secondary tasks were significantly higher at roundabouts than at intersections. This is a surprising result given that roundabouts are complex types of intersections that impose high driving task demands, especially at the during-intersection stage (circulating flow). Note, however, that possible confounding effects may have stemmed from the presence of stationarity, intersection priority and control factors in the comparison of roundabouts with other intersection types. Both intersection locality (urban/rural) and turning directions (left/right/straight) exerted no significant effect on the proportions of time that the drivers allocated to secondary task engagement (Table 6).

**Table 5.** Presence of statistically significant differences in proportions of time allocated to secondary tasks based on driver-related factors (*p < 0.05, **p < 0.0005)

| Driver-related factor | % of total intersection time | % of upstream time | % of during time | % of downstream time | % of moving time | % of stationary time |
|---|---|---|---|---|---|---|
| Gender | | | | | | |
| Age | ** | ** | ** | ** | ** | * |

**Table 6.** Presence of statistically significant differences in proportions of time allocated to secondary tasks based on situational factors (*p < 0.05, **p < 0.0005)

| Situational factor | % of total intersection time | % of upstream time | % of during time | % of downstream time | % of moving time | % of stationary time |
|---|---|---|---|---|---|---|
| Intersection control | * | ** | | | | * |
| Intersection priority | | | | | | * |
| Intersection type | | | * | * | * | |
| Intersection locality | | | | | | |
| Turning direction | | | | | | |

## 4. Conclusion

This paper presents a novel application of the ND approach in the examination of driver engagement in secondary tasks at intersections. The findings on prevalence showed that 30.6% of the total intersection time was associated with secondary task engagement. The comprehensive data analysis indicated that the drivers engaged selectively in secondary tasks in accordance with changes in the demands imposed by driving and roadway situations. The drivers exercised self-regulation by reducing their engagement with secondary activities during more demanding driving situations. This self-regulatory behaviour was represented by the V-shaped relationship between the proportions of time devoted to secondary task engagement across the three intersection stages and the greater willingness of the drivers to engage in such activities when their vehicles were stationary than when the vehicles were moving. The behaviour was also reflected by the diminished willingness of the drivers to engage in secondary tasks when they did not have priority and when they travelled along intersections managed with traffic signs. A particularly important finding is that the elderly drivers were less likely to engage in secondary tasks than the younger drivers.

The results can serve as guidelines for the development of safety measures intended for traffic systems at intersections. They also offer the preliminary information needed to improve driver training/education and awareness programmes on managing distractions and safe driving strategies, especially for novice drivers. Finally, the findings can contribute to the creation of guidelines for classifying intersections in terms of the prevalence and self-regulation of secondary task engagement. These guidelines can be established on the basis of the resultant broadened understanding of who engages in secondary tasks at intersections, when these tasks are executed, what types of tasks drivers occupy themselves with and where such tasks are implemented.

Further research is planned to expand the dataset and further scrutinise the concerted effects of other individual or collective situational factors on drivers' secondary task engagement at intersections. Another initiative under way is the development of a mechanism for using speed data as continuous variables rather than considering them only as binary variables (i.e. moving versus stationary). A limitation worth noting is that no baseline epochs for non-intersection-related behaviours were adopted in this work. Although an examination of upstream and downstream areas of intersections uncover insights, these will not be representative of driving outside intersections.


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