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Driving context influences drivers' decision to engage in visual–manual phone tasks: Evidence from a naturalistic driving study

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ABSTRACT

Introduction: Visual–manual (VM) phone tasks (i.e., texting, dialing, reading) are associated with an increased crash/near-crash risk. This study investigated how the driving context influences drivers' decisions to engage in VM phone tasks in naturalistic driving. *Method:* Video-recordings of 1,432 car trips were viewed to identify VM phone tasks and passenger presence. Video, vehicle signals, and map data were used to classify driving context (i.e., curvature, other vehicles) before and during the VM phone tasks ($N = 374$). Vehicle signals (i.e., speed, yaw rate, forward radar) were available for all driving. *Results:* VM phone tasks were more likely to be initiated while standing still, and less likely while driving at high speeds, or when a passenger was present. Lead vehicle presence did not influence how likely it was that a VM phone task was initiated, but the drivers adjusted their task timing to situations when the lead vehicle was increasing speed, resulting in increasing time headway. The drivers adjusted task timing until after making sharp turns and lane change maneuvers. In contrast to previous driving simulator studies, there was no evidence of drivers reducing speed as a consequence of VM phone task engagement. *Conclusions:* The results show that experienced drivers use information about current and upcoming driving context to decide when to engage in VM phone tasks. However, drivers may fail to sufficiently increase safety margins to allow time to respond to possible unpredictable events (e.g., lead vehicle braking). *Practical applications:* Advanced driver assistance systems should facilitate and possibly boost drivers' self-regulating behavior. For instance, they might recognize when appropriate adaptive behavior is missing and advise or alert accordingly. The results from this study could also inspire training programs for novice drivers, or locally classify roads in terms of the risk associated with secondary task engagement while driving.

1. Introduction

Driver distraction is widely acknowledged as one of the leading causes of crashes and a major concern for traffic safety (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Stutts, Reinfurt, Staplin, & Rodgman, 2001; Wang, Knipling, & Goodman, 1996). Distraction can be defined as a diversion of attention away from activities critical for safe driving toward a competing activity (Lee, Young, & Regan, 2008). Recent naturalistic studies promise cutting-edge insights into the mechanisms underlying distraction. For instance, the 100-car naturalistic driving study (100-car study) has demonstrated that complex secondary tasks that require several manual inputs and/or several glances away from the road are associated with an increased risk of crash and near-crash involvement (Dingus et al., 2006; Klauer et al., 2006). Visual–manual (VM) phone tasks such as dialing, sending a text message, or reading are associated with an increased risk of crash/near-crash involvement (Klauer et al., 2006; Olson, Hanowski, Hickman, & Bocanegra, 2009), while talking on the phone seems to have a neutral or even protective effect (Hickman & Hanowski, 2012; Klauer et al., 2006; Olson et al., 2009). Evaluating drivers' crash/near-crash risk while they are performing a task, without considering their exposure to distraction, will only address part of the safety problem.

The exposure to driver distraction (i.e., how often and for how long drivers are engaged in different secondary tasks) influences the number of crashes where distraction can be considered a contributing factor (Young & Regan, 2008). There are several factors that influence the exposure and overall risk of crash/near-crash involvement (Dingus, Hanowski, & Klauer, 2011), such as driver risk adaptation, driver state, and how frequently—and in what situations—drivers engage in potentially risky behavior. For instance, dialing a phone number in low traffic density on a motorway may not impose an increased risk, while the same task may be risky in high traffic density where other vehicles are likely to brake or change lanes. In the IVBSS naturalistic study, Funkhouser and Sayer (2012) found that drivers are more likely to engage in VM phone tasks when standing still. This finding suggests that secondary task engagement does not occur randomly. A driver may use different strategies to decide whether, and when, to engage

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in VM tasks (Lee, Regan, & Young, 2008; Schömig & Metz, 2013). Improved understanding of drivers' exposure to secondary tasks can improve the ability to estimate both crash/near-crash risk and the safety impact of driver distraction (Dingus et al., 2011). These issues point to the central questions of this paper: in which situations do drivers choose to engage in VM phone tasks?

1.1. Willingness to engage in secondary tasks

Lerner, Singer, and Huey (2008) investigated drivers' willingness to engage in secondary tasks, using an on-road study and focus groups. They found that task-related motivation was more important than the immediate or upcoming driving situation, although maneuvers such as exits, merges, and turns were identified as having some influence. Many drivers report that they do not engage in secondary tasks in poor weather, on winding roads, in heavy traffic, at night, or close to schools (Young & Lenné, 2010). In contrast, Horrey and Lesch (2009) found that drivers did not strategically adapt the timing of secondary tasks to areas of low demand when driving on a closed test-track they were familiar with, and no other vehicles were present. Additionally, young drivers are more likely than mature drivers to initiate VM phone tasks while driving (Funkhouser & Sayer, 2012; Pöysti, Rajalin, & Summala, 2005).

1.2. Timing of secondary tasks

There is little research on how secondary task engagement is influenced at the tactical level (i.e., task timing). It is, however, likely that drivers adapt their task timing based on immediate and upcoming driving task demand. For instance, if a driver only dials while stopped, it is likely that this driver will initiate the task just after slowing down to a complete stop. Other driving maneuvers, such as sharp turns or overtaking, may also influence the timing of secondary task initiation.

1.3. Driver adaption to driving and secondary task demand once engaged in a secondary task

At the operational level, drivers can use different strategies to manage the demands of the driving task and secondary tasks. Firstly, a driver may reduce the amount of effort invested in the driving task by permitting degraded driving performance. Several driving simulator and on-road experiments have demonstrated that VM tasks influence driving performance and safety, in the form of reduced lane-keeping performance (Engström, Johansson, & Östlund, 2005; Hosking, Young, & Regan, 2009; Törnros & Bolling, 2005), higher variations in distance to lead vehicle (Hosking et al., 2009), impaired event detection (Törnros & Bolling, 2005), and increased reaction times to sudden events (Kircher et al., 2004).

Secondly, while engaged in a secondary task, drivers can also modulate their attention to the secondary task depending on the demand of the driving tasks. For VM tasks, this is reflected by a change in glance behavior. For instance, the driver takes shorter glances away from the road when driving demand increases, both in driving simulator studies (Tsimhoni, Smith, & Green, 2004) and naturalistic driving (Tivesten & Dozza, 2014).

Thirdly, drivers can reduce driving demand by increasing safety margins themselves during secondary tasks. Several driving simulator studies have demonstrated that drivers reduce speed (Engström et al., 2005; Törnros & Bolling, 2005) and increase time headway to a lead vehicle (Hosking et al., 2009) when engaged in a VM secondary task. However, in a naturalistic driving study analyzed by Fitch et al. (2013), drivers sending a text message did not seem to reduce speed, although they did increase time headway to the lead vehicle. It is not known whether this adaptation (or self-regulation) occurs as a consequence of secondary task demand once the driver is engaged in the task, or as a preparation before the task is initiated.

1.4. Research questions

This study investigated how driving contexts (with different driving demands) influence drivers' decision to engage in VM secondary tasks, using naturalistic driving data to address the following research questions: (a) What driving contexts influence the overall propensity to engage in VM phone tasks? (b) For those drivers who do engage in VM phone tasks, which driving contexts influence the task timing? (c) Do drivers self-regulate, that is, adapt the demand of the driving task before or after the task is initiated, to increase their safety margins?

2. Materials and methods

2.1. The Swedish EuroFOT database for passenger cars

This study analyzed naturalistic driving data collected from 100 Volvo cars for one year as part of the EuroFOT project. The cars were driven in real traffic by the primary drivers and other members of the household. The drivers all resided in the Gothenburg region of Sweden. No advanced driver assistance system was activated during the first 3–4 months of driving, which are the data used in this study. Cameras (forward road view, rearward road view, and driver view), on-board sensors, and the CAN-bus were used to collect continuous data at 10 Hz. Data collection covered trips in their entirety, that is, from ignition of the motor to when the motor was shut down. Approximately 1 million km was recorded and stored in a database that included information about the 198 drivers who participated in the study ($M = 45.3$ years, $SD = 10.8$ years, 57% male, 43% female). More information on driver demographics and the data collected can be found in Sanchez et al. (2012).

A few CAN-bus signals were selected, either to corroborate the video coding (see Sections 2.2–2.3) or for inclusion directly in the analysis (see Section 2.4). These signals were yaw rate (deg/s), speed (km/h), gear (category), forward radar (m), and line crossings (category). Yaw rate was used as an indicator of turning maneuvers. Speed and gear signals were used to establish speed distributions and to distinguish reversing from forward motion. The forward radar was used to measure distance to a lead vehicle and calculate time headway in car-following. A lead vehicle was considered to be present if the radar signal could be interpolated into a smooth signal indicating a distance to another vehicle of 150 m or less. The line crossing signal indicated whether line markings were crossed, either to change lanes or overtake.

2.2. Selection of trips and general coding of whole trips

A 5-week period of data collection during late spring 2010 was targeted for analysis. There were approximately 6,000 trips in the database during this time period. Three analysts viewed and coded entire trips (from start to end), which were randomly selected from the 6,000 trips. Each trip was coded according to the categorical variables *purpose of trip*, *passengers*, *light conditions*, and *phone-related sequence*, itemized in Table 1. A trip was not coded if: (a) it was extremely short (i.e., less than 30 s), (b) forward or driver video was missing, or (c) the vehicle was not in traffic (e.g., car wash, car service). The available resources allowed for coding of 1,432 trips with a total of 391 h of driving (trip duration: $M = 984$, $Mdn = 626$, $SD = 1309$ s). In total, 103 different drivers were observed from different age groups (18–29 years ($N = 9$), 30–55 years ($N = 77$); 56–65 years ($N = 14$); unknown age ($N = 3$)), and gender (61 males; 42 females). Out of all coded trips, 193 trips presented at least one VM phone task (i.e., dialing, texting, or reading). A total of 374 VM phone tasks were identified in the dataset. All coding was performed using an updated

Table 1
Categorical variables obtained from video coding or processing of CAN-data for all hours of driving, all phone tasks at the time of task initiation, and a subset of phone tasks.

	Time driving (391 h) [% of time]	All phone tasks (N = 374) [% of tasks]	Phone tasks[a] with ≥15 s baseline (N = 275) [% of tasks]
Purpose of trip[b]			
Vacation or leisure	15.4%	9.4%	9.5%
Commute	23.6%	22.7%	23.6%
Shopping	7.1%	8.8%	11.6%
Picking up or leaving children	1.8%	0.8%	0.4%
Unknown	52.1%	58.3%	54.9%
Passengers[b]			
Yes	47.6%	16.8%	18.2%
No	52.4%	83.2%	81.8%
Light conditions[b]			
Daylight	94.1%	92.5%	91.6%
Dusk or dawn	1.8%	4.3%	4.7%
Dark	4.1%	3.2%	3.6%
Phone-related sequence[b]			
Baseline	0.60%	N/A[c]	N/A[c]
Suspend	0.19%	N/A[c]	N/A[c]
Other	98.58%	N/A[c]	N/A[c]
Total (no visual–manual phone task):	*(99.37%)*		
Dialing	0.19%	51.6%	46.9%
Texting	0.18%	11.0%	12.4%
Reading	0.17%	33.7%	37.8%
Texting or reading[d]	0.09%	3.7%	2.9%
Total (visual–manual phone task):	*(0.63%)*	*(100.0%)*	*(100.0%)*
Driving[f]			
Going straight on road	N/A[e]	58.3%	57.8%
Going straight at intersection	N/A[e]	2.4%	2.2%
Wide curve (R = 500–1000 m)	N/A[e]	8.8%	9.5%
Narrow or medium curve (R < 500 m)	N/A[e]	12.3%	10.9%
Turning at intersection	N/A[e]	1.9%	1.5%
Roundabout	N/A[e]	0.8%	0.7%
Standing still — in traffic	N/A[e]	4.0%	4.4%
Standing still — parked	N/A[e]	7.5%	9.5%
Lane change	N/A[e]	2.9%	2.5%
Overtaking	N/A[e]	0.8%	0.7%
Other	N/A[e]	0.3%	0.4%
Road type[f]			
Motorway/highway	N/A[e]	28.9%	26.9%
Rural	N/A[e]	44.4%	47.6%
Urban	N/A[e]	19.8%	18.2%
Other	N/A[e]	7.0%	7.3%
Lead vehicle present (radar)[g]			
Yes	42.0%	39.0%	40.7%
No	58.0%	61.0%	59.3%
Lead vehicle present[f]			
Yes	N/A[e]	48.1%	49.8%
No	N/A[e]	51.9%	50.2%
Oncoming vehicle present[f]			
Yes	N/A[e]	14.4%	14.2%
No	N/A[e]	85.6%	85.8%
Weather conditions[f]			
Rain	N/A[e]	14.7%	15.3%
Snow	N/A[e]	0.0%	0.0%
Fog	N/A[e]	0.3%	0.4%
Clear	N/A[e]	85.0%	84.4%
Traffic density[f]			
Low (including parked)	N/A[e]	68.7%	68.7%
Medium	N/A[e]	24.3%	23.3%
High	N/A[e]	4.0%	4.4%
Stop&go	N/A[e]	2.9%	3.6%

[a] Subset included in task-timing analysis.
[b] Categorical variable, coded, time series at 10 Hz during whole trips.
[c] Only applicable to VM phone tasks.
[d] When it was not possible to distinguish between texting and reading or when performed as a single merged task.
[e] Only coded for phone-related sequences.
[f] Categorical variable, coded, time series at 10 Hz during phone tasks and baseline.
[g] Categorical variable, processed CAN-data, time series at 10 Hz.

version of FOTware (Dozza, Moeschlin, & Léon-Cano, 2010), an analysis tool developed for naturalistic driving data.

The variable *purpose of trip* was coded once per trip and categorized as *vacation or leisure*, *commute*, *shopping*, *picking up or leaving children*, and *unknown*. Trip purpose was inferred from where the trip started or ended (e.g., shopping mall), the presence of passengers (e.g., children), what the driver wore (e.g., flip-flops), geographic location through GPS and other clues (e.g., presence of caravan trailer). All the primary drivers shared the same employer and working location, which made it easy to identify many of the commuting trips. If there were no obvious clues about the purpose of the trip, it was coded as *unknown*. This variable was transformed to a time series at 10 Hz as before the analysis.

The variable *passengers* was coded as a binary variable (i.e.: yes, no) and indicates whether at least one passenger was present. Passengers were identified from the driver video, which showed part of the front passenger seat and part of the rear seat. This variable was coded as a time series at 10 Hz since the driver sometimes stopped during the trip to pick up or drop off a passenger.

The variable *light condition* was categorized as *daylight*, *dusk or dawn* and *dark*, and coded as a time series since it sometimes changed during the trip. The categories *daylight* and *dark* were in general easy to determine, but it was not always obvious when dawn turned into daylight in the morning or when dusk turned into dark in the evening. At the end of all coding work, all trips that involved changes in light condition were reviewed once again to make the coding for *dusk and dawn* as consistent as possible.

The variable *phone-related sequence* was coded as a time series to identify any sequence where the driver performed a VM phone task that lasted for at least 3 s. The VM phone tasks were categorized as *dialing*, *texting*, *reading*, and *texting or reading* and differentiated by the interactions with the phone buttons (or display) and the activities after the task (e.g., talking). The category *texting or reading* was only used when it was not possible to determine if the driver interacted with the phone buttons while reading on the phone screen, or when reading and texting tasks were performed in a continuous sequence that was then considered a single merged task. The category *baseline* was coded to include the 30 s of driving immediately prior to each VM phone task. This duration could be shorter than 30 s, if the driver initiated the VM phone task shortly after another phone activity or shortly after the start of the trip. The baseline segments mostly contained attentive driving, although any type of secondary task could be present as long as it was not phone-related (e.g., talking, ending call, texting). If the driver momentarily suspended the VM phone task for at least 3 s, it was coded as *suspend*.

The start and end of each VM phone task were defined by the very beginning of the first off-road glance (defined according to ISO (2002)) and the end of the last off-road glance that were related to that task. Glance coding was not performed in this study, but the drivers' glance behavior was observed in the driver video in order to locate the start and end of each VM phone task.

2.3. Detailed coding performed for phone-related sequences

Whenever the analysts identified a VM phone task, they performed more detailed coding, assigning the categorical variables *driving*, *road type*, *lead vehicle present*, *oncoming vehicle present*, *weather conditions*, and *traffic density*. These variables, itemized in Table 1, were all coded as time series at 10 Hz. The detailed coding was performed for every phone-related sequence that included one VM phone task and one baseline segment.

The *driving* variable was used to categorize both the local road environment and the drivers' movements in relation to it. Road segments away from intersections were divided into three groups depending on curve radius ($R < 500$ m, $R = 500–1000$ m, $R > 1000$ m). A curve radius larger than 1,000 m was considered a straight road segment. To quantify each curve's radius, analysts used a combination of forward video, GPS, maps[1] and curve radius estimation based on yaw rate, according to Eq. (1).

$$R_{CURVE} = V_{CAR}/(\omega * \pi/180) \quad (1)$$

In Eq. (1), R_{CURVE} is the estimated curve radius (m), V_{CAR} is the car velocity (m/s), and ω is the yaw rate (deg/s).

[1] http://maps.google.se, http://www.eniro.se.

The variable *road type* was categorized as *motorway/highway* or *rural* if the posted speed limit was higher than 50 km/h. If roads had a median barrier they were classified as *motorway/highway*; otherwise they were classified as *rural*. Any road with a posted speed limit of 50 km/h or lower was categorized as *urban*. The category *other* included parking areas, driveways, and construction zones, and was independent of the posted speed limit.

The variable *lead vehicle present* was categorized as a binary variable (i.e., yes, no). A lead vehicle was considered present if it was traveling in the same lane and within 150 m of the subject vehicle. Car-following was coded using the forward camera view, and the forward radar measured the distance to the vehicle ahead.

The variable *oncoming vehicle present* was categorized as a binary variable (i.e., yes, no), and coded to identify situations when one or more vehicles were approaching the subject car from the opposite direction. An oncoming vehicle was only considered present if all of the following conditions were met: (a) it was visible in the front view camera, (b) it was less than 3 s away from passing the subject car, and (c) the road did not have a median barrier.

The variable *weather condition* was coded using the forward camera view. The variable was categorized as *rain*, *snow*, *fog*, and *clear*. The categories *rain* and *snow* were coded in case of visible precipitation, and *fog* was coded if visibility was reduced by fog. All other weather conditions were coded as *clear*.

The variable *traffic density* was categorized as *low*, *medium*, *high*, and *stop&go*. Free flow traffic where other vehicles' speed was not influencing the subject vehicle's speed was coded as *low* traffic density. A traffic flow where the driver could choose his/her own speed with some restrictions, including performing periodic lane changes, was categorized as *medium*. If the speed was clearly limited by other vehicles but the traffic flow was fairly stable, it was categorized as *high* traffic density. Finally, *stop&go* described traffic situations where the vehicle alternated between stopping and traveling slowly.

2.4. Analysis

The analysis of drivers' decision to engage in a VM phone task was performed in three parts, presented in the three subsections below.

2.4.1. Descriptive analysis

A descriptive statistical analysis was performed for all VM phone tasks ($N = 374$), for a subset of VM phone tasks included in the analysis of task timing (see Section 2.4.3) ($N = 275$), and for all hours of driving during whole trips ($N = 391$ h). The category variables *purpose of trip*, *passengers*, *light conditions*, *phone-related sequence*, and *lead vehicle present (radar)* were included. Frequency distributions for these variables were presented in two ways: as the percentage of VM phone tasks at the time of task initiation, and as the percentage of driving time for all trips. The remaining coded variables *driving*, *road type*, *oncoming vehicle present*, *weather conditions*, *traffic density*, and *lead vehicle present* were only available and presented for the VM phone tasks.

2.4.2. Analysis of overall propensity to engage in a VM phone task

The overall propensity to engage in VM phone tasks (considering all drivers together) was investigated for the variables that were available for whole trips in the dataset, including coded variables (i.e., *purpose of trip*, *passengers*, *light conditions*, and *phone-related sequence*) and CAN-data (i.e., car speed, absolute value of yaw rate, lead vehicle presence as estimated by the forward radar). The continuous variables (i.e., car speed, absolute value of yaw rate) were organized in bins to enable the same type of statistical tests as were used for the categorical variables.

Frequency distributions for the investigated category variables were plotted as the percentage of VM phone tasks at the time of task initiation compared to the percentage of all hours of driving from whole trips.

One-sampled chi-square tests (Henriksson, 2008) were used to compare VM phone tasks to all driving for those categories that presented a clear difference between the plotted graphs. The chi-square tests compared the observed number of VM phone tasks where a category was present at the time of task initiation to the expected (or theoretical) number of tasks. The latter was computed as the total number of VM phone tasks multiplied by the percentage of driving time (from all 1,432 trips in their entirety) where this category was present. The tests were corrected for multiple testing using the Benjamini and Hochberg false discovery rate (Benjamini & Hochberg, 1995).

2.4.3. Analysis of VM phone task timing

VM phone task timing was investigated to determine whether the driver modified the timing of VM phone tasks in relation to changes in driving context. This analysis included a subset of the VM phone tasks (N = 275). They all contained at least 15 s of baseline driving before the VM phone task (see Section 2.4.1). Four consecutive five-second intervals were defined, covering 15 s prior to task initiation and 5 s after task initiation. The percentage of the investigated phone-related sequences during which a variable category was present was plotted across the four time intervals for different driving contexts (described by the variables *driving*, *lead vehicle present*, and *oncoming vehicle present*). For each of these variables, a category was assigned as present during a five-second interval if it was present for at least 30% of the time.

Another subset of phone-related sequences was specifically selected to analyze time headway and speed in car following. This subset (N = 76) included all sequences in which the subject car was moving, a lead vehicle was present, and there were readings from the forward radar in all four time intervals.

The percentage of phone-related sequences (N = 275) with at least one line crossing was plotted for each of the four time intervals. Additionally, mean yaw rate was plotted across the four time intervals for all phone-related sequences in which the subject car was moving in all four intervals (N = 217).

Within the same phone-related sequences, matched (pairwise) comparisons were performed for the second time interval (starting 10 s before VM phone task initiation) and the fourth time interval (starting at task initiation). The third time interval (i.e., 5 s before task initiation) was not used for the comparison because it commonly included drivers reaching for the phone as preparation for performing the VM phone task. The McNemar test was performed for all category variables (e.g., turning at intersection, standstill in traffic). Wilcoxon signed rank test was performed for continuous variables (e.g., speed, yaw rate) by comparing mean values across time intervals. The tests were corrected for multiple testing using the Benjamini and Hochberg false discovery rate (Benjamini & Hochberg, 1995).

3. Results

3.1. Descriptive statistics

Table 1 provides an overview of the data used for statistical analysis of drivers' overall propensity to engage in a VM phone task (presented in Section 3.2). The table also presents a comparison between all VM phone tasks (N = 374) and the subset of VM phone tasks (N = 275) used in the analysis of VM phone task timing (presented in Section 3.3). The variables *purpose of trip*, *passengers*, *light conditions*, *phone-related sequence*, and *lead vehicle present (radar)* were available for all driving. They are presented in the first data column in Table 1 as a percentage of all driving time (N = 391 h) for which a category is present.

The distributions of category variables for the VM phone tasks are also presented in Table 1. The middle column shows the percentage of all VM phone tasks where a category is present, and the right column shows the percentage of VM phone tasks in the subset used for analyzing task timing. These data include all the variables based on video coding and CAN-data that describe driving context and passenger presence. The subset of VM phone tasks was quite similar to all VM phone tasks in the distributions of the investigated categorical variables, although it contained a lower proportion of dialing tasks. The tasks that were not included in this subset either occurred at the very beginning of the trip (N = 24), or shortly after another phone-related activity, such as talking on the phone or texting (N = 75). Most of the VM phone tasks occurred in clear weather conditions, in low traffic density, and on rural roads, motorways or highways. On average, drivers engaged in VM phone tasks 0.63% of their driving time (including standstill).

3.2. Effect of speed, driving context, and passenger presence on the overall propensity to engage in a VM phone task

The overall propensity to engage in a VM phone task was investigated by comparing driving context at task initiation to all 391 h of driving. Fig. 1 compares the general speed distribution from all trips with the speed distribution at task initiation. VM phone tasks was more likely to be initiated while standing still ($\chi^2(1, N = 374) = 23.82$, $p \leq 0.001$), and less likely at speeds above 120 km/h ($\chi^2(1, N = 374) = 8.54$, $p \leq 0.01$). No VM phone tasks were initiated while reversing.

The yaw rate was below 2 deg/s in 87% of the VM phone task initiations and in 77% of the driving time from all trips ($\chi^2(1, N = 374) = 23.63$, $p \leq 0.001$). VM phone tasks were less likely to be initiated when a passenger was present, as was the case in 16.8% of all VM phone tasks and in 47.6% of all driving ($\chi^2(1, N = 374) = 142.16$, $p \leq 0.001$). There was no clear influence of daylight or dark light conditions on the overall propensity to engage in a VM phone task, although a VM phone task was slightly more likely to be initiated at dusk or dawn compared to other light conditions. Dusk or dawn was present in 4.3% of the VM phone tasks and 1.8% of the driving time from all trips ($\chi^2(1, N = 374) = 13.38$, $p \leq 0.001$).

Lead vehicle presence did not have a clear influence on the overall propensity to engage in a VM phone task, since a lead vehicle was present in 39.0% of all VM phone tasks and in 42.0% of all driving time as estimated by the forward radar ($\chi^2(1, N = 374) = 1.34$, $p > 0.05$).

There were minor differences in the overall propensity to engage in a VM phone task, depending on the purpose of the trip. The only clear difference was that VM phone tasks were likely to be initiated during vacation or leisure, a category accounting for 9.5% of all VM phone tasks and 15.4% of all driving time ($\chi^2(1, N = 374) = 10.38$, $p \leq 0.01$).

3.3. Effect of driving context and speed on VM phone task timing

Fig. 2 shows how different driving contexts changed during four consecutive five-second time intervals before and after the drivers initiated a VM phone task.

3.3.1. Speed

Fig. 2a shows the percentage of drivers standing still, while parked or in traffic. There was a statistically significant effect of drivers waiting to initiate a VM phone task until after parking and reaching a complete stop ($Freq_{t2} = 5.5\%$, $Freq_{t4} = 10.9\%$, $p \leq 0.001$, the paired odds ratio is 16.0), while there was no significant effect for standing still in traffic on task timing ($Freq_{t2} = 5.1\%$, $Freq_{t4} = 5.5\%$, $p > 0.05$, the paired odds ratio is 1.5). Speed was stable before and after task initiation ($M_{t2} = 64.7$ km/h, $M_{t4} = 65.2$ km/h; $Mdn_{t2} = 68.0$ km/h, $Mdn_{t4} = 68.0$ km/h, N = 217, $p > 0.05$) for tasks where the car was moving in all four time intervals. Thus, some drivers decided to park the car before engaging in a VM phone task, while drivers who did not stop did not adapt their speed.

3.3.2. Turning

Turning maneuvers influenced the timing of drivers' decisions to initiate in a VM phone task. There was a statistically significant effect

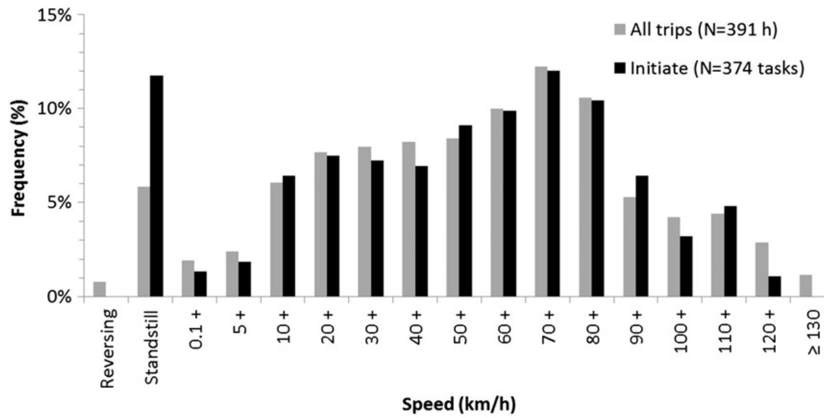

Fig. 1. Speed distribution for all hours of driving and when initiating a VM phone task.

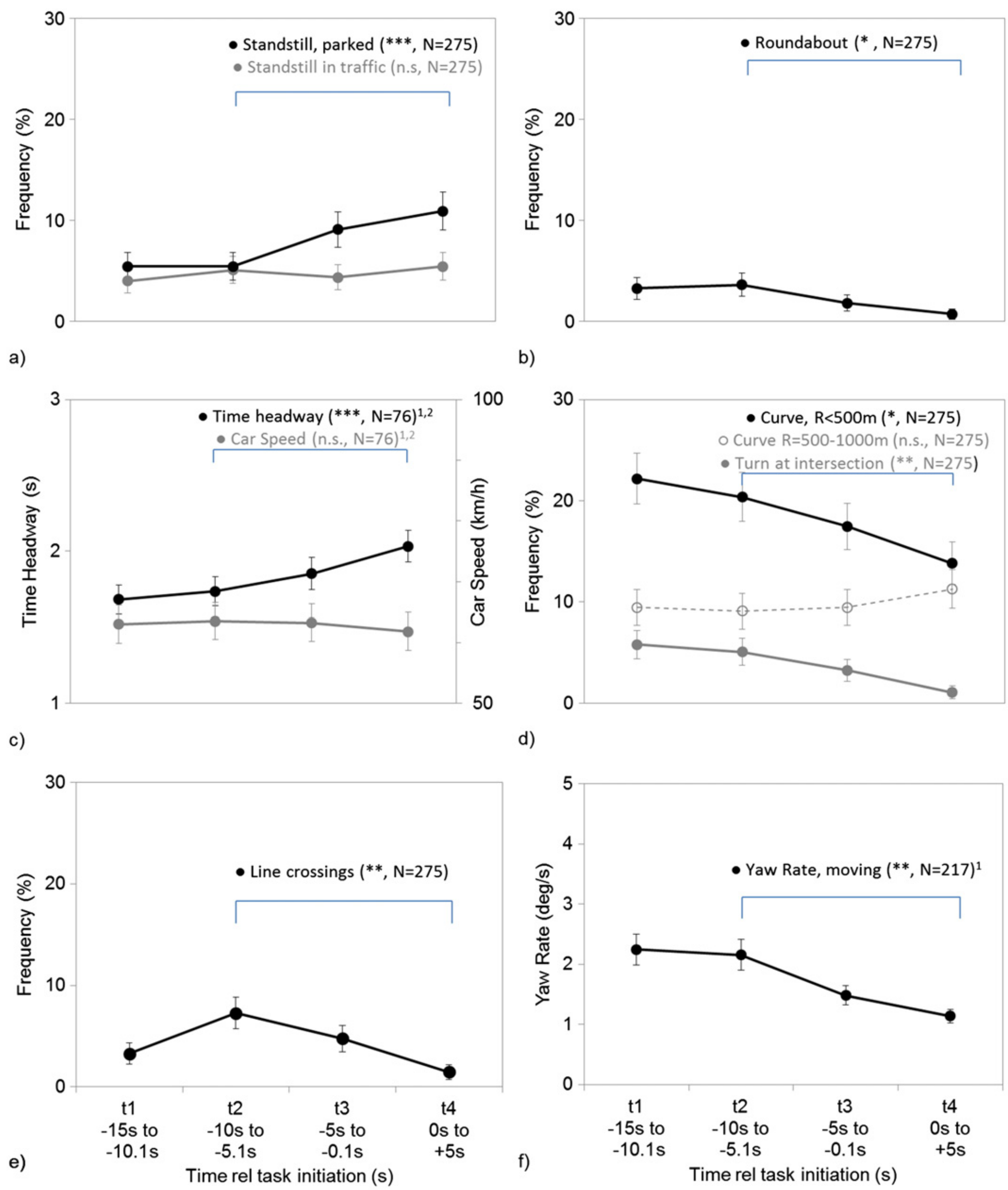

Fig. 2. Driving context variables (y-axis) for the phone-related sequences including driving before and during the VM phone task. The y-axis either shows the percentage of phone-related sequences where a driving context was present, or the mean value for continuous variables. The x-axis shows four consecutive time intervals starting 15 s before VM phone task initiation. The horizontal lines show the results of pairwise comparisons, indicating statistically significant results at the 5%(*), 1%(**), or 0.1%(***) level. The error bars show standard error of mean, or standard error of point estimates.

of drivers waiting to initiate a VM phone task until after passing a sharp curve ($R < 500$ m) ($Freq_{t2} = 20.4\%$, $Freq_{t4} = 13.8\%$, $p \leq 0.05$, the paired odds ratio is 0.51), after turning at an intersection ($Freq_{t2} = 5.1\%$, $Freq_{t4} = 1.1\%$, $p \leq 0.01$, the paired odds ratio is 0.08; Fig. 2d), and after passing a roundabout ($Freq_{t2} = 3.6\%$, $Freq_{t4} = 0.7\%$, $p \leq 0.05$, the paired odds ratio is 0.11; Fig. 2b). There were, however, no statistically significant differences for wider curves ($R = 500$–1000 m; $Freq_{t2} = 9.1\%$, $Freq_{t4} = 11.3\%$, $p > 0.05$, the paired odds ratio is 1.35). Overall, the drivers tended to wait until after completing a sharp turn to initiate a VM phone task. The mean absolute yaw rate was consequently significantly lower after task initiation than before when considering phone-related sequences where the car was in motion during all four time intervals ($M_{t2} = 2.16$, $M_{t4} = 1.14$ deg/s; $Mdn_{t2} = 0.75$, $Mdn_{t4} = 0.62$ deg/s, $z = -3.050$, $p \leq 0.01$; Fig. 2f).

3.3.3. Car following

Fig. 2c shows speed and time headway for sequences with lead vehicle present, forward radar measurements available, and subject car moving in all four time intervals prior to and during VM phone tasks. Speed was only slightly lower after task initiation than before, and not significantly different ($M_{t2} = 63.5$ km/h, $M_{t4} = 61.8$ km/h; $Mdn_{t2} = 68.1$ km/h, $Mdn_{t4} = 66.7$ km/h, $z = -0.564$, $p > 0.05$). Time headway, on the other hand, was significantly higher after task initiation than before ($M_{t2} = 1.74$ s, $M_{t4} = 2.03$ s, $Mdn_{t2} = 1.59$ s, $Mdn_{t4} = 1.88$ s, $z = -4.204$, $p \leq 0.001$). Thus, drivers tended to wait for the lead vehicle to speed up and move further ahead before engaging in VM phone tasks.

3.3.4. Line crossings

Fig. 2e shows the percentage of sequences with line crossings before and after VM phone task initiation. Line crossings indicate overtaking and/or lane changes. The percentage was significantly higher before task initiation than after ($Freq_{t2} = 7.3\%$, $Freq_{t4} = 1.5\%$, $p \leq 0.01$, the paired odds ratio is 0.20). Thus drivers waited to complete a lane-change or overtaking maneuver before engaging in a VM phone task.

3.3.5. Contextual variables not influencing VM phone task initiation

There were a few context variables that showed little to no change in relation to the timing of VM phone task initiation. Drivers did not seem to adjust their timing to the simple presence of a lead vehicle. However, the percentage of lead vehicles present before task initiation was slightly lower than after ($Freq_{t2} = 49.1\%$, $Freq_{t4} = 50.9\%$, $p > 0.05$), reflecting the possibility that drivers may have settled into the desired lane after a lane change or overtaking and before initiating the VM phone task. Task timing was not dependent on the presence of oncoming vehicles when considering the second time interval ($Freq_{t2} = 21.8\%$, $Freq_{t4} = 22.5\%$). The presence of oncoming vehicles was only slightly more common just before task initiation ($Freq_{t3} = 25.5\%$) rather than after ($Freq_{t4} = 22.5\%$), indicating that drivers may delay task initiation a few seconds when an oncoming vehicle is approaching. Each oncoming vehicle is only present for a few seconds. Another unexpected finding was that drivers did not seem to adjust the timing of task initiation when they were going straight through an intersection: this situation was equally common before and after task initiation ($Freq_{t2} = 3.3\%$, $Freq_{t4} = 3.3\%$, $p > 0.05$).

4. Discussion

This paper used naturalistic driving data to determine the extent to which driving context influences the overall propensity to engage in VM phone tasks, and drivers' timing of VM phone tasks. The results show that driving context and the presence of passengers do indeed influence the overall propensity to engage in VM phone tasks. Further, driving context also influenced drivers' timing of VM phone tasks. For instance, drivers waited to engage in VM phone tasks until after completing sharp turns. Countermeasures to crashes, including advanced driver assistance systems, training programs, and infrastructure design, should take these results into account by supporting and possibly boosting drivers' natural adaptations to secondary tasks.

4.1. Overall propensity to engage in VM phone tasks depends on driving context

Several factors influenced the overall propensity to engage in VM phone tasks. It seems that drivers who intend to engage in a VM phone task may refrain from driving with excessive speed and that they may to some extent choose to perform VM phone task when standing still. The speed distribution for all driving and VM phone tasks in this study nicely resembles the speed distributions from Funkhouser and Sayer (2012). The findings on the overall propensity to initiate VM phone tasks in the present study suggest that drivers adapt their VM phone task engagement to the driving demand, and the purpose of this adaptation may be to increase their safety margin to compensate for the increased risk from distraction.

Passenger presence strongly influenced how likely it was for a VM phone task to be initiated. This confirms findings from a survey study in which drivers reported that they were less likely to use the phone while driving when a passenger was present (Walsh, White, Watson, & Hyde, 2007). Some drivers reported that they were more safety-cautious, while other drivers considered it rude to engage in other tasks when a passenger is present, according to a focus group study performed by Lerner et al. (2008). It seems that both safety and social concerns may influence how likely a driver is to engage in a VM phone task when a passenger is present.

The purpose of the trip had a minor influence on the propensity to initiate a VM phone task, a finding most likely due to varying communication needs when going to work, going shopping, or on vacation. Light conditions did not seem to influence the overall propensity to initiate a VM phone task, with the exception of dusk and dawn where it was slightly more likely. One possible explanation for this result is that drivers are sensitive to changes in the light conditions. For instance, when it is getting dark drivers may feel the need to dial or send a text message to communicate that they are late. This finding should, however, be interpreted with caution, since dusk and dawn were quite rare and difficult to code precisely.

The presence of a lead vehicle did not seem to influence the overall propensity to initiate a VM phone task, which suggests that lead vehicles are not perceived as particularly threatening so they do not necessarily induce self-regulation for secondary tasks. One explanation may be that drivers are more cautious in situations that change, as opposed to steady state driving. Generally, car-following goes on for a long time and is performed at close-to-constant speed and headway. This finding suggests that drivers engaged in VM tasks while car-following can benefit from information and early alerts advising of rapidly decreasing headways (e.g. forward collision warning sensitive to visual distraction, deceleration from adaptive cruise control).

4.2. Timing of VM phone tasks depends on driving context

The drivers who did engage in VM phone tasks adjusted the task timing with respect to several contextual factors. The drivers waited to initiate a VM phone task until after completing different types of high-demand driving maneuvers (e.g., sharp turns, roundabouts). This adaptive behavior of task timing clearly suggests that drivers are aware of the increased risk from VM phone tasks while driving. Negotiating sharp turns is associated with high visual demand (Tsimhoni & Green, 1999) since the driver has to estimate curvature, control steering (Land & Lee, 1994; Lappi, Lehtonen, Pekkanen, & Itkonen, 2013), and check for potential threats such as oncoming vehicles (Lehtonen, Lappi, & Summala, 2012). Lane change and overtaking maneuvers are also associated with high driving demand: the driver has to decide when to start the maneuver, and monitor other vehicles in order to judge their speed, distance, trajectory, and drivers' intentions (Polus, Livneh, & Frischer, 2000; Portouli, Nathanael, Marmaras, & Papakostopoulos, 2012; Salvucci & Liu, 2002). Thus, in general drivers compensate for high driving demand by waiting to engage in VM phone tasks. This behavior is guided by the necessity to share limited visual information when performing VM phone tasks.

Many of the observed drivers decided to park the car before initiating the VM phone task. This result suggests that drivers made a strategic decision either to pause in their driving or wait until they reach their destination before they initiate the VM phone task. It was surprising to find that standing still in traffic (e.g., when waiting at red traffic light) had no clear effect on task timing, since this has been identified in focus groups as a good opportunity to make calls (Lerner et al., 2008). However, it is possible that there is an adaptation of task timing to standing still in traffic that was not revealed, due to the constraints of the analysis. Some drivers may stand still for longer than 15 s before they initiate the task. Another explanation, which was actually observed in a few cases, was that some drivers initiated the VM phone tasks while still braking, thus anticipating the standstill condition. Consequently, it cannot be ruled out that drivers used the strategy to perform VM phone tasks while standing still in traffic, even though it was not revealed in the present study.

The presence of a lead vehicle did not influence the timing of VM phone tasks. The drivers did, however, initiate VM phone tasks when time headway to the lead vehicle was increasing and the driver was keeping close-to-constant speed. Consequently, drivers may not be sensitive to the presence of a lead vehicle in steady state driving, but when time headway increases as a consequence of the lead vehicle increasing speed, it may be perceived as a good opportunity to perform a VM phone task.

Surprisingly, going straight at intersections did not seem to influence the drivers' timing of VM phone tasks. Drivers did not need to perform a visually demanding turning maneuver, and most of the time they had the right of way (e.g., green light, main road). As a result, they may have felt relatively secure. However, intersection crashes are commonly caused by another vehicle without the right of way entering the intersection (Sandin, 2009). This result implies that drivers who are engaged in a VM task when entering an intersection are particularly vulnerable to rare and unexpected events.

4.3. Adaptation of driving task demand

The finding that drivers tended to maintain speed while engaged in VM phone tasks contrasts several driving simulator studies (Engström et al., 2005; Törnros & Bolling, 2005). However, it is in line with a previous naturalistic study (Fitch et al., 2013) that reported no reduction of speed for text messaging. This result suggests that drivers do not actually reduce driving task demand as a consequence of secondary task demand. Instead, they plan ahead, initiating the VM phone task when the driving demand is relatively low.

4.4. Strengths and limitations of using naturalistic driving data to study drivers' decision to engage in VM tasks

The results from this study show that naturalistic driving data are an excellent source for studying genuine driver behavior in real traffic, without the influence of predefined tasks, instructions, and artificial driving environments that are common in experimental settings. Continuously collected naturalistic driving data from whole trips contain a large amount of data on normal driving. Thus, naturalistic driving data provide detailed information about actual real-world driving behavior that cannot be obtained in an experimental setting or from self-report methods such as questionnaires and focus groups (af Wåhlberg, Dorn, & Kline, 2010; Lajunen & Özkan, 2011).

Naturalistic data collection itself has some limitations, since the recording is active only while the ignition is turned on. This means that any pre-trip preparations and tasks performed just before or after the trip are not available for analysis. This means, for instance, that the percentage of drivers who wait to perform a VM phone task until after they park the car is likely much higher in reality than shown in this study, since drivers may also turn off the ignition before performing the task. Furthermore, it was commonly observed that drivers were already talking on the phone when the recording of the trip started, suggesting that some of the drivers decided to make a call before starting the car. This behavior could not be verified with the present data.

Furthermore, naturalistic observations cannot reveal the influence of intrinsic factors such as social norms, attitudes, and internal processes (e.g., thoughts, time pressure), while focus groups and surveys can. In other words, naturalistic driving data are useful for studying what drivers actually do in real-world driving, while focus groups and surveys are useful for studying why drivers act as they do.

Three analysts performed the video coding, and inter-coder reliability is an important consideration. In the present study, the analysts frequently reviewed and discussed each other's coding of phone-related sequences to ensure consistent interpretation of the variables and to clarify coding instructions when needed. One trip was coded separately by all three analysts, and their results were compared. In general, the analysts' coding agreed well, but there were some situations where they coded differently. These differences included whether a minor intersection on a main road should be classified as a straight road segment or an intersection, whether oncoming vehicles should be classified as present when there was a median barrier for only part of the road, and whether a lead vehicle should be classified as present when it was approximately 150 m ahead of the subject car and there were no reliable measurements from the forward radar. These situations highlight the fact that there is a great deal of variation in driving contexts in naturalistic driving that is not always easily classified. Therefore, checking for inter-coder reliability should preferably be used as an integral part of the working process when training new analysts and developing coding instructions (Klauer, Perez, & McClafferty, 2011).

The selection of drivers and vehicles in naturalistic driving studies is often biased, covering a restricted geographical area and including a limited number of drivers who may not be representative of the driving population. The current data were mainly collected in the region around the city of Gothenburg. As noted, the primary drivers were all employees at the same company, and most of them were middle-aged males. Other members of the same households were also driving the cars, which provided more data from young drivers and female drivers. However, there were very few young drivers, and no truly novice drivers, who are of special concern for safety (Lee, 2007). There would probably be a higher prevalence of VM phone tasks in the present study if there had been a higher proportion of young drivers, more closely resembling the driver population in Sweden.

The current study provides a first-order analysis of the context variables that influenced VM phone task engagement. Future studies, using more advanced analysis methods, could reveal to what extent these variables correlate and interact to influence drivers' decision to engage in VM tasks. Furthermore, a dataset with more data for each individual driver could also provide additional insights, such as how often and in what situations different drivers engage in this type of tasks.

4.5. Implications for safety research and countermeasure development

The results from the current study show that drivers' exposure to VM phone tasks (i.e., how often and under what circumstances they choose to engage) does not occur at random. It is self-regulating behavior, a consequence of choices made by the driver at the tactical and strategic levels. This knowledge can be used to improve crash/near-crash risk estimates and safety impacts associated with different driving situations and driver behaviors. This is essential for prioritizing which problems and situations to target for advanced driver assistance systems. Improved estimates about driving exposure, crash/near-crash risk, and safety impact can also identify which driving scenarios are more suitable for evaluating the safety of different secondary tasks, in-vehicle user interfaces, and countermeasures.

Drivers seem to be skilled in deciding when to engage in secondary tasks when the current and upcoming driving demand is highly predictable from visual input (e.g., upcoming curves). However, they may not have the same safety concerns when the potential changes in driving demand are less predictable (e.g., lead vehicle braking, another vehicle entering the intersection without the right of way). The design of advanced driver assistance systems could be inspired by a better understanding of the drivers' self-regulating behavior. For instance, these systems could boost (or simply help drivers maintain) their self-regulating behavior, by recognizing when such behavior is missing and acting accordingly. Informing and alerting drivers may be especially important when the driver is engaged in a secondary task and the driving situation suddenly and unexpectedly changes. The combination of inattention and an unexpected event, such as a lead vehicle braking, has certainly been pointed out as a common mechanism in conflicts with a lead vehicle in the 100-car study (Dingus et al., 2006). Advanced driver assistance systems can enhance traffic safety by using sensors that can detect information on both driving context and driver state (i.e., level of attention and vigilance). This information could be used to customize warnings about the driving environment based on the driver's state. For instance, a forward collision warning could activate earlier than normal if the driver is distracted.

This study shows that drivers are aware of the increased risk from VM tasks and are skilled at counterbalancing these risks with increased safety margins (i.e. waiting for a less demanding driving context). However, this skill may come with experience and thus may not be present in novice drivers. The results in this paper identify several driving contexts with increased risk and several effective self-regulating strategies that may be useful for training novice drivers.

Different driving contexts may be the consequence of infrastructure design (e.g. road curvature). The results presented in this paper cannot only inform the design of new infrastructure but also help categorize different types of infrastructure according to the risks incurred by secondary tasks. This categorization may be important because new regulations may locally prohibit or allow different phone tasks depending on the classification of the infrastructure.

4.6. Task interruption and recurring individual patterns

The drivers in the present study were frequently observed suspending the VM phone tasks in periods of high driving demand; in some cases, drivers did not resume the task afterward. Although circumstances for task interruption were not specifically analyzed, they could reveal important information in future research.

In fact, the interruption of secondary tasks is likely to be a more accurate indicator of drivers' comfort zone boundaries (Ljung Aust & Engström, 2011) than VM phone task initiations. Thus situations that fall outside the drivers' comfort zone could be identified, leading to the development of high-acceptance indicators and thresholds for driver support systems providing real-time feedback in the form of warnings or automatic control of the vehicle. These systems could also be used to train novice drivers.

Another possible use of naturalistic driving data is investigating recurring patterns for individual drivers. For instance, do drivers have specific favorite spots where they usually make calls? If they do, it would suggest that there is a strategic adaptation of task initiation based on knowledge about the road. In a closed test-track experiment, drivers did not strategically adapt their decision to engage in secondary tasks to road segments with low driving demand, even though they were familiar with the road geometry (Horrey & Lesch, 2009). However, it is possible that studying usage patterns for individual drivers in naturalistic driving could reveal different results, since drivers engage in secondary tasks in real traffic based on their actual need to perform the task and their familiarity of the road. The information about how drivers decide to devote specific spots to making phone calls can inform the design of driver assistance systems as well as infrastructure: for instance, some stretches of road may be built to allow for secondary tasks, regulating phone use instead of banning it.

5. Conclusions

This study analyzed naturalistic driving data to investigate drivers' engagement in visual–manual (VM) phone tasks. It was less likely that a VM phone task was initiated during high driving task demand (e.g., high speed, sharp turns) or when a passenger was present, and more likely while standing still. The presence of a lead vehicle did not influence the overall propensity of VM phone task; however, drivers commonly initiated VM phone tasks when a lead vehicle was increasing speed, resulting in increased time headway. The drivers also waited to initiate VM phone tasks until after making sharp turns and lane change maneuvers, while there was no effect of going straight at intersections on task timing. The drivers tended to maintain speed before and during the VM phone tasks. Consequently, exposure to secondary tasks does not occur at random.

Drivers seem to be skilled in deciding when to engage in secondary tasks, based on current and upcoming driving demand that is highly predictable from visual input (e.g., upcoming curves), but they may not have the same safety concerns for potential changes in driving demand that is less predictable (e.g., lead vehicle braking). Advanced driver assistance systems should favor and possibly boost drivers' self-regulating behavior, for instance by recognizing when such adaptive behavior is missing and act accordingly. Informing and alerting drivers may be especially important when the driver is already engaged in a VM task and the driving situation suddenly changes (e.g., lead vehicle braking) because the driver is more likely to suffer severe consequences due to distraction. The results presented in this paper also identify a few specific driving contexts and driver self-regulating strategies that could be targeted during the training of novice drivers. Finally, some of the results in this paper could contribute to the creation of guidelines to locally classify roads in terms of the risk associated with secondary task engagement while driving.

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