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Using SHRP 2 naturalistic driving data to assess drivers' speed choice while being engaged in different secondary tasks

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Abstract

Introduction: The engagement in secondary tasks while driving has been found to result in considerable impairments of driving performance. Especially texting has been suspected to be associated with an increased crash risk. At the same time, there is evidence that drivers use various self-regulating strategies to compensate for the increased demands caused by secondary task engagement. One of the findings reported from multiple studies is a reduction in driving speed. However, most of these studies are of experimental nature and do not let the drivers decide for themselves to (not) engage in the secondary task, and therefore, eliminate other strategies of self-regulation, e.g., postponing the task. Goal of the present analysis was to investigate if secondary task engagement results in speed adjustment also under naturalistic conditions. *Method:* Our analysis relied on data of the SHRP 2 naturalistic driving study. To minimize the influence of potentially confounding factors on drivers' speed choice, we focused on episodes of free flow driving on interstates/ highways. Driving speed was analyzed before, during and after texting, smoking, eating and adjusting/ monitoring radio or climate control; in a total of 403 episodes. *Results:* Data show some indication for speed adjustment for texting, especially when driving with high speed. However, the effect sizes were small and behavioral patterns varied considerably between drivers. The engagement in the other tasks did not influence drivers' speed behavior significantly. *Conclusions and practical applications:* While drivers might indeed reduce speed slightly to accommodate for secondary task engagement, other forms of adaptation, e.g., strategic decisions, might play a more important role in a natural driving environment. The use of naturalistic driving data to study drivers' self-regulatory behavior at an operational level has proven to be promising. Still, in order to obtain a comprehensive understanding about drivers' self-regulatory behavior, a mixed-method approach is required.

Keywords: Naturalistic driving; Distraction; Self-regulatory behavior; Speed adjustment; Interstate/ highway

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1 Introduction

Driver distraction is a problem that has become one of the most pressing issues in road safety in recent years. In addition to "traditional" secondary tasks, such as eating, drinking and smoking, technological developments in the past decade have led to an introduction of new forms of distraction, caused by the interaction with mobile devices, such as navigation systems, mp3 players or cell phones. One of the activities that has spread considerably, especially among young drivers, is to read and write text messages while driving. In a survey of young adults in the United States, 72.5% of the respondents reported that they text while driving at least some of the time (Nelson, Atchley, & Little, 2009). Similar results have been found in the United Kingdom (Lansdown, 2009), where, when asked about their engagement in distracting activities while driving, 41% of the participants admitted to write and 62% to read text messages. These numbers are alarmingly high, especially given that texting is seen as one of the most dangerous distracting activities even by the drivers themselves (e.g., Lansdown, 2006; Young & Lenné, 2010). Results from driving simulator studies support this sentiment, as they show that texting while driving can lead to, e.g., longer reaction times (e.g., Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; Yannis, Laiou, Papantoniou, & Christoforou, 2014), more lane deviations (e.g., Drews et al., 2009; Hosking, Young, & Regan, 2007; Rudin-Brown, Young, Patten, Lenné, & Ceci, 2013) and an increased crash risk (e.g., Drews et al., 2009; Yannis et al., 2014).

At the same time, there is some evidence that drivers compensate for the increased demand through various self-regulating strategies. Fuller (2005), e.g., hypothesized that drivers act in a way that allows them to maintain a specific, self-defined level of preferred task difficulty (with the task being, in this case, the combination of driving and secondary task operation). How drivers set this specific level of difficulty is influenced by perceived capabilities (e.g., driving skills), motivation for behavioral adaptation (e.g., motivation for speed reduction, which results from factors such as the available time for a trip) and effort motivation (e.g., motivation to effectively implement the behavioral adaptation). To maintain the preferred level of difficulty, drivers employ strategic decisions as well as adjustments in driving behavior at an operational level.

With regard to strategic decisions, previous research gives some indication that drivers try to engage in highly demanding secondary tasks only in contexts where the driving task demand is low. It has been found in focus groups and surveys that secondary task operation (e.g., using cell phones, MP3 players or navigation systems, eating/ drinking, interaction with passengers) is avoided, e.g., when driving in the dark (e.g., Thulin & Gustafsson, 2004; Young & Lenné, 2010), in dense traffic (e.g., Thulin & Gustafsson, 2004; Young & Lenné, 2010) or under bad weather conditions (e.g., Young & Lenné, 2010). At an operational level, there is evidence that drivers try to reduce the driving task demand by an adjustment in driving behavior. Such behavioral adjustments include, e.g., an increase of distance to the lead vehicle (e.g., Hosking et al., 2007; Ishida & Matsuura, 2001; Strayer & Drews, 2004) and a reduction of lane changes (e.g., Beede & Kass, 2006) during secondary task operation such as cell phone conversation and texting. One of the most replicated findings in this context is, however, the reduction of speed. For example, in a driving simulator study of Haigney, Taylor and Westerman (2000), driving speed during cell phone conversation was about 2 km/h lower than in the pre-call period and about 4 km/h lower than in the post-call period. Similar results were reported in another simulator study (Rakauskas, Gugerty, & Ward, 2004), in which cell phone conversations in a rural driving environment led to a significant speed reduction of about 1 km/h compared to driving without conversation. Patten, Kircher, Östlund and Nilsson (2004) were able to show a significant reduction of mean speed in real traffic. When participants had to answer a phone call while driving on a motorway, they reduced speed about 1.5 km/h during the conversation compared to non-distracted driving. Similar results have been reported from a driving simulator study for tasks such as reading and writing text messages, which led to a decrease in driving speed on rural and urban roads compared to driving without secondary task (Yannis et al., 2014).

While all these results clearly point towards some form of self-regulatory behavior, the cited studies suffer from the fact that their experimental nature, be it in the driving simulator or the field, limits the ecological validity of their results. Driving situations in such studies are usually designed explicitly to elicit performance degradation or behavioral adaptation. In addition to that, drivers normally cannot decide against engaging in the secondary task. Most of the time, they are required to operate the task in predefined situations, without the choice to postpone the task to some later point in time. Hence, while the studies successfully showed self-regulatory behavior at an operational level, they did so by depriving the driver of the opportunity to compensate through strategic decisions. Therefore, the question arises of whether self-regulatory behavior at an operational level can be found under naturalistic driving conditions, when drivers can freely decide (not) to engage in a specific secondary task. To address this question, the use of data collected in a so called Naturalistic Driving Study (NDS) appears to be the most appropriate approach.

1.1 Naturalistic driving studies

Compared to experimental approaches, NDS are much better able to provide insight into different aspects of everyday driving behavior. Vehicles (often participants' own vehicles) are equipped with a data acquisition system that records relevant information about driver behavior, vehicle characteristics and external conditions. Such a system usually consists of multiple cameras, sensors that collect variables, such as speed or vehicle position, and a storage unit. Drivers are then required to use their car as they normally would, with the system acquiring data, e.g., on their day-to-day trips to work, to the mall or on vacation over a longer period of time.

In NDS, there are neither experimenter nor experimental interventions that constantly remind the driver of participating in a research study (van Schagen & Sagberg, 2012). Instead, drivers are observed passively in their natural driving behavior (see e.g., van Schagen et al., 2011). This is especially important in the analysis of driver distraction, as engagement in secondary tasks is usually a self-directed activity. Drivers decide on their own when to text or make a call and this decision is certainly influenced by motivational aspects regarding the task (e.g., how important it is to send the text message in the next few minutes) as much as it is regulated by contextual factors (e.g., the complexity of the current traffic situation). Experimental designs can hardly account for that. At the same time, it has to be acknowledged that the absence of experimental control makes it difficult to establish causal relationships (van Schagen & Sagberg, 2012).

In recent years, naturalistic driving data have been used to investigate driver distraction and inattention, especially with regard to its prevalence and its consequences for road safety. For example, Stutts et al. (2005) examined the engagement in distracting activities of 70 drivers whose vehicles were equipped with different video cameras for a period of one week. They found that drivers were distracted in 14.5% of the total time in which the vehicles were moving (including secondary tasks such as using the cell phone, eating/ drinking or reading/ writing; excluding simple conversations with passengers) and that these distractions often resulted in adverse vehicle events (e.g., lane wandering, lane encroachment and sudden braking). Others have assessed the relationship between driver distraction and inattention and (near-) crash involvement with the help of data from the large scale 100 Car NDS (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Their analysis showed that drivers who frequently engaged in secondary tasks while driving (e.g., talking/ listening on cell phone, eating, reading, applying make-up), were much more often involved in inattention-related crashes and near-crashes (i.e., safety critical events where the driver was drowsy or engaged in some type of secondary task) than drivers who did not. Victor et al. (2015), who used data of the second Strategic Highway Research Program (SHRP 2) NDS, were able to clarify that especially visually distracting activities, such as texting, increase the risk for crashes and near-crashes. However, it appears that only few have used naturalistic driving data to examine driver behavior with regard to self-regulation while being engaged in a potentially distracting activity. Fitch et al. (2013) used matched event samples to compare speed with and without engagement in (cell phone related) secondary tasks. The analysis uncovered speed reduction for a few selected subtasks. Tivesten and Dozza (2015) analyzed speed before and after the initiation of visual-manual phone tasks (e.g., dialing, reading, texting) and found no speed reduction. However, the datasets of both studies included a variety of road types, traffic contexts and speed levels, so that a considerable influence of other factors on speed choice must be assumed. Fitch et al. (2013), e.g., cautioned the readers that “observed speed differences may be from drivers choosing to engage in a cell phone subtask as they approach a stop” (p. 53). It seems that a higher level of homogeneity among analyzed driving situations is required to investigate if self-regulatory behavior at the operational level of driving does indeed exist.

1.2 Research objectives

Aim of the study presented in this paper was to investigate self-regulatory behavior in terms of speed adjustment due to secondary task operation while driving under naturalistic conditions. For the analysis presented in this paper, we used data of the SHRP 2 NDS. Under this research program, a total of 3,247 drivers, in age categories ranging from 16 to 99 years, from six different regions in the United States were observed on their day-to-day trips, in most cases for one or two years (Blatt et al., 2015). Overall, the data set contains about two petabytes of video material, about 50 million miles of travel and about one million hours of driving data (Dingus et al., 2015).

The secondary tasks that were investigated included (1) texting, (2) smoking, (3) eating and (4) adjusting/ monitoring the radio or climate control, with the focus on texting. Given the fact that texting has been found to be one of the most visually, manually and cognitively demanding secondary tasks (e.g., Libby & Chaparro, 2009; Young & Salmon, 2012), we hypothesized that drivers would reduce their speed when texting to maintain an adequate level of task difficulty. Smoking, eating and adjusting/ monitoring the radio or climate control were selected as reference tasks. Although these secondary tasks also occur frequently in everyday driving situations (e.g., Royal, 2003; Stutts et al., 2005), studies indicate that, e.g., eating leads to fewer driving errors compared to visually and cognitively demanding secondary tasks (Jenness, Lattanzio, O'Toole, & Taylor, 2002). Similar results were found for radio tuning, which also appears to be relatively harmless for driving performance (Lee, Roberts, Hoffman, & Angell, 2012). Consequently, smoking, eating and adjusting/ monitoring the radio or climate control should elicit much less (or even no) self-regulatory behavior than texting, i.e., any speed reduction to accommodate for these tasks would be expected to be lower than the speed reduction caused by texting.

To be able to observe potential changes in speed as a result of secondary task engagement, it is important that the influence of other factors that might impact on the drivers' choice of speed is held at a minimum. As a consequence, we decided to focus our analysis on interstate/ highway driving. Several studies indicate that drivers often engage in secondary tasks while driving on interstates or high-speed highways. Johnson, Voas, Lacey, McKnight and Lange (2004) found a total distraction rate of 4% on a high-speed highway by analyzing digital photographs of vehicles and their drivers. Naturalistic driving data also showed that drivers are more likely to, e.g., dial, answer or talk/ listen on cell phones when driving on interstate-like roads as compared to other types of roadway (Stutts et al., 2003). As driving on highways is usually not impeded by intersections, oncoming traffic, non-motorized road users etc., it can be assumed that this type of infrastructure would provide a rather controlled environment for the analysis of potential behavioral adaptation to secondary task engagement on an operational level as compared to, e.g., urban areas, where a large number of additional factors can come into play.

2 Method

2.1 Sampling

For inclusion in our analysis of driver speed in relation to secondary task operation, the situations in which drivers were engaged in such a secondary task had to meet a set of requirements. Beyond the requirement that secondary task operation needed to occur on interstate/ highway (in the following only called "interstate"), initiation and/ or conclusion of secondary task engagement also had to occur on the interstate and be preceded/ succeeded by a sufficient amount of interstate driving, too. In addition, in order to be part of our analysis, secondary task engagement needed to start and/ or end under free flow driving conditions. While it could be expected that, e.g., a lot of drivers engage in secondary tasks while they are stuck in a traffic jam, it is just as clear that under such conditions, no adaptation of speed would occur.

To identify situations which met our requirements, we used the SHRP 2 NDS event database, in which safety critical events (i.e., crashes and near-crashes) as well as baselines episodes (i.e., episodes of driving without a safety critical event, for more details see also Transportation Research Board, 2013) had been annotated along multiple variables, including secondary task engagement (see Table 1 for the relevant secondary task categories and definitions) and driving environment (variable called "locality", of which "interstate/ bypass/ divided highway with no traffic signals" was one potential value). Overall, the SHRP 2 event data base includes more than 32,500 baseline episodes, of which about 8,300 occurred on interstates. The secondary tasks "adjusting/ monitoring radio" and "adjusting/ monitoring climate control" as well as "cell phone – texting" and "cell phone – browsing" (as annotated in the database) were highly similar (and often hard to distinguish). As a consequence, we combined them for further analysis to one category each: "adjusting/ monitoring radio or climate control" and "texting".

Table 1: Description of secondary task categories.

Secondary task category	Description*
(1) Smoking	
Smoking cigar/cigarette	Subject vehicle driver has a lit cigar/cigarette either in their mouth or hand.
(2) Eating	
Eating without utensils	Subject vehicle driver has food that will be put in his/her mouth and a utensil is not used to place the food in the driver's mouth.
(3) Adjusting/ monitoring radio or climate control	
Adjusting/monitoring radio	Subject vehicle driver interacts with in-vehicle radio/audio system either by touching the radio buttons on dashboard or steering wheel, or glancing at the radio on dashboard.
Adjusting/monitoring climate control	Subject vehicle driver interacts with in-vehicle climate control system either by touching the climate control buttons, glancing at the climate control on dashboard, or adjusting climate control vents.
(4) Texting	
Cell Phone – Texting	Subject vehicle driver is pressing buttons or a touch screen on the cell phone to create and/or send a text message.
Cell Phone – Browsing	Subject vehicle driver is pressing buttons or a touch screen on the cell phone to browse the internet or phone applications. May also include voice commands (e.g., Siri).

Notes. *Out of SHRP 2 Researcher Dictionary for Video Reduction Data, available at https://insight.shrp2nds.us/.

2.2 Validation and annotation

As the annotation in the SHRP 2 event data only covers a time window of 6 s, additional video review was required. A first step in this review was the validation of the annotated secondary task. While the largest portion of tasks was annotated appropriately, there were also a few instances in which a task was categorized incorrectly. These episodes were removed from further analysis.

In a next step, we identified secondary task initiation and secondary task conclusion. For our planned analysis, we were not interested in the fine-grained differentiation of different task elements, such as the fact that "texting" would usually be preceded by "reaching for phone", a level of detail as it occurs in the SHRP 2 coding scheme. As our interest lay in the general question of whether drivers would adapt their behavior in order to accommodate for the engagement in a certain secondary task, any activity directed towards this task was considered as being part of the task. For texting, that meant that the first movement of the hands and/ or the first direction of glance (whatever occurred first) towards the phone (i.e., before grabbing it and starting to text) was defined as task initiation. Similarly, task conclusion was defined as the clear cessation of any activity directed towards the task. For texting, in most cases that meant putting away the phone. As soon as the drivers' hand was in a position that made it clear that this positioning was no longer related to the phone (e.g., hand back on the steering wheel or in the drivers' lap), the task was considered to have ended. Initiation and conclusion of smoking, eating and adjusting/ monitoring radio or climate control were defined likewise.

Once we had identified task initiation and conclusion, we verified (through an inspection of the forward view videos) that there was a sufficient portion of free flow interstate driving before (after) the task was initiated (concluded). Through video review, we confirmed that other traffic did not interfere with the drivers' speed selection (either because the distance to a vehicle ahead was too long to be considered relevant or because other traffic was completely absent). For some of the trips, these requirements were only met for either initiation or conclusion of secondary task engagement. While we did not remove such trips from the analysis completely, we only used that portion of the secondary task episode (i.e., initiation or conclusion) for which the requirements were fulfilled. Therefore, the number of initiation periods differs from the number of conclusion periods.

Once we had identified a set of episodes for analysis, we annotated interruptions of task operation and other concurrent secondary tasks. An interruption occurred when the driver had apparently concluded secondary task engagement (according to our previous definition), only to re-engage in the same task within a short period of time. For texting, e.g., that meant that the driver had put away the phone, only to pick it up again a few seconds later to continue to text. A clear cut definition was difficult here. We found multiple instances in which drivers appeared to "converse" through texting, i.e., apparently sending a text, putting away the phone, picking it up again not much later, appearing to read a message, texting again and so on. We tried to ensure that there was at least 30 s without engagement in the respective secondary task before or after the analyzed portion of the trip (i.e., we gave the driver the chance to normalize his driving behavior, in case behavioral adaptation had been occurred due to secondary task operation, before the next potential engagement in the respective secondary task). Other concurrent secondary tasks (i.e., task type, initiation and conclusion) were annotated for the period 30 s before, during and 30 s after the driver had engaged in the secondary task of interest. Concurrent secondary tasks most often occurred during smoking (e.g., adjusting the radio while holding the cigarette). A secondary task often observed before or after eating was, not surprisingly, drinking.

After we had completed the annotation, we went back to the previously discarded episodes and reviewed the complete trip to find other usable instances of texting. This was done in order to increase the sample size of texting episodes for the analysis. Once we had found a candidate episode, it was reviewed the same way as described above. Table 2 shows the final numbers of episodes per secondary task category that were used in the analysis.

Table 2: Numbers of episodes per secondary task category before and after validation. In column “overall”, the total number of different episodes included in the analysis of a secondary task is listed; columns “initiation period” and “conclusion period” contain the actual number of episodes analyzed for the respective period of task engagement (e.g., for texting 192 episodes were analyzed, among them 155 episodes for the initiation and 159 episodes for the conclusion period).

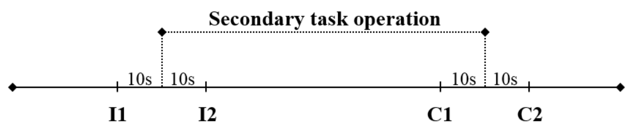
Secondary task category	**Original (before validation)**	**Overall (after validation)**	**Initiation period**	**Conclusion period**
(1) Texting	249	192	155	159
(2) Smoking	69	42	22	32
(3) Eating	141	75	39	67
(4) Adjusting/ monitoring radio or climate control	186	94	86	85

Note. 44 of the 192 texting episodes were found after additional review of full trips for originally discarded episodes.

2.3 Data analysis

In order to assess drivers' self-regulatory behavioral adaptation, we examined (1) if speed was decreased when drivers initiated the secondary task and (2) if speed was increased again after secondary task operation was over. To do that, simulator or field experiments, which provide a rather high control over driving environment and engagement in secondary tasks, often compare the average speeds before, during and after secondary task operation (e.g., Haigney et al., 2000; Patten et al., 2004; Schömig, Metz, & Krüger, 2011). In a naturalistic driving dataset, however, durations of secondary task operation might differ vastly and driving environments can change rapidly, so averaging speed did not appear to be an appropriate approach. Instead, we analyzed the speed 10 s before initiating and 10 s after initiating the secondary task (i.e., analysis of the initiation period) as well as 10 s before concluding and 10 s after concluding secondary task operation (i.e., analysis of the conclusion period). For simplicity, these points of measurement will be referred to as I1 (10 s before initiation), I2 (10 s after initiation), C1 (10 s before conclusion) and C2 (10 s after conclusion) in the remainder of this article (see Figure 1 for a visualization). The 10 s before/ after time window was chosen as a compromise between trying to keep the driving context as homogeneous as possible (which would require the smallest possible window) and giving drivers a chance to actually adapt their speed (which would require a larger window). It appears reasonable to assume that, if any behavioral adaptation occurs, it would very probably not have started 10 s before the task and would be in full progress or even completed 10 s after initiating the task (the same applies to the conclusion of secondary task operation).

Figure 1: Visualization of the analysis approach.



When the total secondary task duration was shorter than 20 s (which occurred exclusively for texting and adjusting/ monitoring radio or climate control), the point of measurement was moved to the "center" of secondary task operation (e.g., for an 8 s task, I2 was 4 s into the task). In order to remove the possibility that such short tasks bias the results, all analyses where then repeated *excluding* any secondary task episodes with a duration shorter than 20 s. These additional analyses showed that for both secondary tasks in questions, the results including and excluding the short episodes were comparable (see Table 4, Appendix A).

As initial speed before initiating a secondary task varied considerably, we decided to analyze episodes with high initial speed levels separately for those secondary tasks for which we had a sufficient number of episodes. As it can be assumed that a higher speed results in a higher driving demand, more self-regulation (i.e., a clearer reduction of speed) would be required to accommodate for secondary task operation. Therefore, we selected those episodes in which initial speed was higher than or equal to the 75 percentile for the respective secondary task, and again assessed potential differences in speed between I1 and I2.

In addition, for each secondary task category we calculated the percentage of episodes for which speed increased by more than 1 km/h, remained approximately at the same level (i.e., varied between -1 km/h to 1 km/h) or decreased by more than 1 km/h after initiating (concluding) secondary task operation from I1 to I2 and C1 to C2. The criterion of 1 km/h was chosen based on findings of different experimental studies (see literature review in section 1).

3 Results

3.1 Sample

Table 3 displays the details of our episode sample for each secondary task category. For all secondary tasks, the sample contained more episodes involving female than male drivers, just as younger drivers appear to be overrepresented. It has to be noted, however, that this should not be interpreted as evidence for a higher prevalence of secondary task operation among these groups of drivers. The composition of the episode sample is the result of both the SHRP 2 sampling strategy for recruiting participants (which, e.g., oversampled younger drivers, see Blatt et al., 2015) and our filtering mechanisms. It is notable, however, that for all investigated secondary tasks, the sample included a few drivers who had reported earlier (before participating in the study; as part of a risk taking questionnaire) that they never engaged in activities such as cell phone use, eating or drinking, putting on makeup, reading or smoking cigarettes while driving in the 12 months prior to the study.

Table 3: Sample description per secondary task category.

	Texting	**Smoking**	**Eating**	**Adjusting/ monitoring radio or climate control**
Episodes	192	42	75	94
Participants	131	32	71	90
Gender				
male	53	13	33	41
female	78	19	38	48
No information	0	0	0	1
Age				
16 – 24 years	94	14	20	44
25 – 34 years	19	6	12	12
35 – 44 years	10	1	5	3
45 – 54 years	5	5	8	4
55 – 64 years	2	0	12	11
65 – 74 years	1	4	8	5
≥ 75 years	0	2	6	9
No information	0	0	0	2
Driving experience				
≤ 10 years	100	17	24	47
11 – 20 years	18	4	9	10
21 – 30 years	5	1	6	2
31 – 40 years	6	4	9	8
41 – 50 years	2	1	9	10
> 50 years	0	5	12	11
No information	0	0	2	2
Reported frequency of secondary task operation in the past 12 months				
Often	53	13	16	9
Sometimes	47	12	27	35
Rarely	23	3	16	32
Never	5	4	4	10
No information	3	0	8	4

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3.2 Texting

Overall, we analyzed 192 episodes of texting (among them 155 episodes of task initiation and 159 episodes of task conclusion) from a total of 131 participants. As some participants were involved in several texting episodes, which could introduce a bias, we repeated all analyses *excluding* drivers that had contributed multiple episodes. The results were comparable to the results of the analyses including all episodes (see Table 4, Appendix A). The same applies for the other secondary tasks.

The duration of the episodes of texting ranged from 8 s to 36 min (including interruptions) and 8 s to 29 min (actual time on task; i.e., excluding interruptions during which participants put away the phone; see Figure 2). On average, texting episodes had a length of about 3 min, both with and without interruptions (*M* = 3.08, *SD* = 4.43 including interruptions; *M* = 2.69, *SD* = 3.85 time on task). In 25 of the analyzed episodes, participants were, at one point, engaged in an additional concurrent secondary task (i.e., another secondary task occurred between initiation and conclusion of texting). In most of these cases, drivers adjusted/ monitored the radio or climate control while texting. In 46 of the episodes, another secondary task occurred between I1 and I2 or C1 and C2 (i.e., another secondary task occurred in the period of 10 s before to 10 s after initiation or in the period of 10 s before to 10 s after conclusion of texting).

Figure 2: Duration of episodes for secondary task "texting".

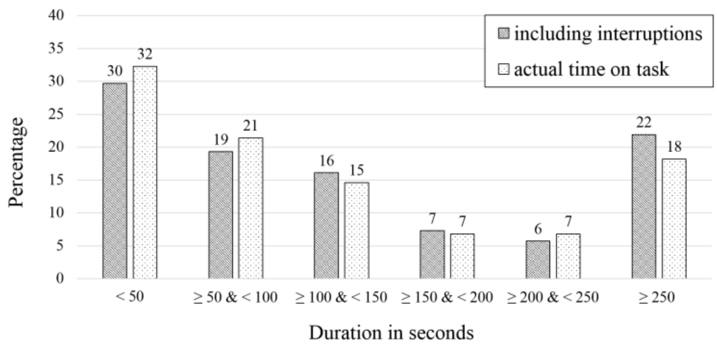

Figure 3 shows the speed for all episodes as well as the high speed episodes at I1, I2, C1 and C2. The difference in speed between I1 and I2 varied from -14.17 km/h to 13.84 km/h, indicating that some

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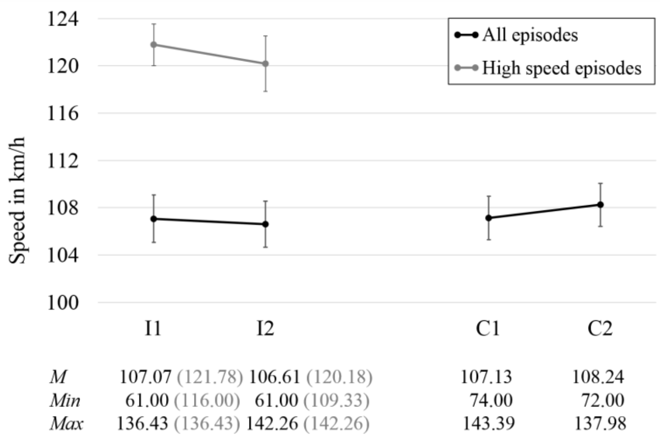
drivers reduced their speed considerably, while others even increased their speed after starting to text. In 35% of the episodes, speed was reduced by more than 1 km/h, in 36% speed remained at approximately the same level and in 28% speed was increased by more than 1 km/h. On average, drivers reduced their speed by 0.46 km/h (*SD* = 5.21) between I1 and I2. However, this speed reduction was not statistically significant ($t(154) = 1.105$, $p = .271$, $d = 0.04$). When looking at the 25% of cases in which speed at I1 was highest (i.e., at or above 115.91 km/h), we found a significant reduction in speed of 1.60 km/h (*SD* = 4.17) between I1 and I2 ($t(37) = 2.360$, $p = .024$, $d = 0.24$, $N = 37$).

Between C1 and C2, we found speed differences between -11.09 km/h and 16.21 km/h. Speed was increased by more than 1 km/h in 41% of the texting episodes, remained at approximately the same level in 26% and was reduced by more than 1 km/h in 32% of all cases. On average, speed was increased significantly by 1.11 km/h (*SD* = 4.94) between C1 and C2 ($t(158) = -2.813$, $p = .006$, $d = -0.10$).

Figure 3: Speed at I1, I2, C1 and C2 for secondary task “texting”.



Note. Error bars represent 95th confidence interval.

3.3 Smoking

For smoking, our dataset for analysis contained 42 secondary task episodes (among them 22 episodes of task initiation and 32 episodes of task conclusion) from 32 participants. Smoking duration ranged from 4 min to 34 min (see Figure 4). On average, participants were engaged in the task for about 8.13

min (*SD* = 5.32). There was no episode in which the cigarette or cigar was put away and picked up again later (which would have qualified as an interruption for this specific secondary task). We found 18 episodes in which another concurrent secondary task occurred while smoking. Again, in most of these cases, drivers adjusted/ monitored the radio or climate control. In 13 episodes another secondary task was performed between I1 and I2 or C1 and C2.

Figure 4: Duration of episodes for secondary task "smoking".

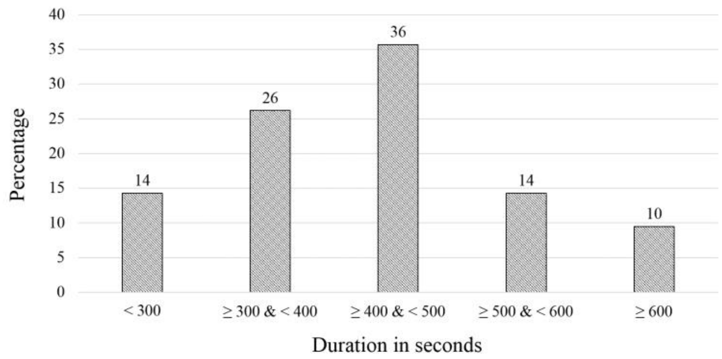
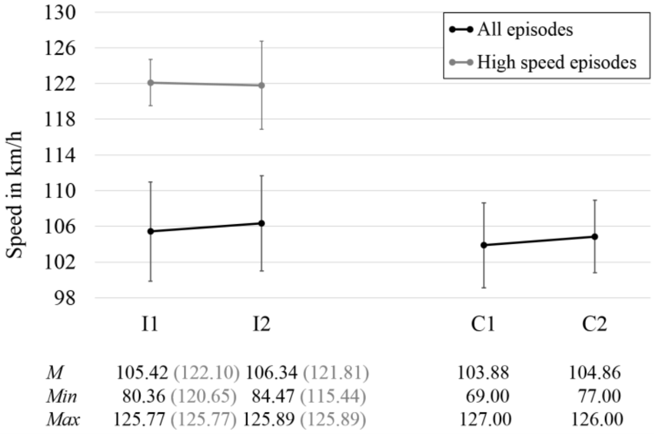


Figure 5 displays the speed at the different points of measurement. The speed differences between I1 and I2 varied from -5.87 km/h to 6.95 km/h. In only 14% of the episodes speed was reduced by more than 1 km/h. In most episodes (46%) speed remained at approximately the same level or even increased by more than 1 km/h (41%). As a consequence, as seen in Figure 5, on average, there was a small increase in speed of 0.92 km/h (*SD* = 3.01) from I1 to I2. However, this difference was not statistically significant ($t(21) = -1.423$, $p = .170$, $d = -0.07$). As the number of analyzable episodes was rather small ($N = 22$), we did not statistically analyze those episodes that had a high initial speed level (at or above 117.91 km/h). On a descriptive level, data of the remaining 5 episodes showed a small speed reduction of 0.29 km/h (*SD* = 3.30) between I1 and I2.

When looking at C1 and C2, we found speed differences that varied from -9.00 km/h to 12.33 km/h. There was an increase in speed of more than 1 km/h in 44% of the episodes. In 28% of the episodes, speed remained at approximately the same level, while in 28% of the episodes it was reduced by more than 1 km/h. There was an average increase in speed of 0.98 km/h (*SD* = 4.31) between C1 and C2, which was not statistically significant ($t(31) = -1.284$, $p = .209$, $d = -0.07$).

Figure 5: Speed at I1, I2, C1 and C2 for secondary task "smoking".

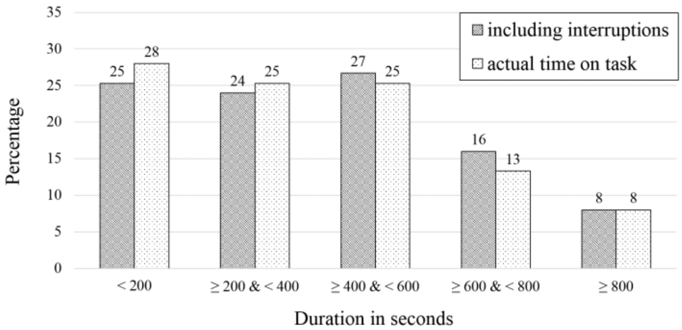


Note. Error bars represent 95th confidence interval.

3.4 Eating

Our analysis of eating covered 75 episodes of secondary task engagement (among them 39 episodes of task initiation and 67 episodes of task conclusion) from 71 drivers. Secondary task duration ranged from 51 s to 27 min (including interruptions) and 48 s to 26 min (time on task; see Figure 6). On average, drivers engaged in eating for about 7 min both with and without interruptions (*M* = 7.21, *SD* = 4.93 including interruptions; *M* = 6.82, *SD* = 4.86 time on task). In 34 episodes drivers performed another concurrent secondary task in the period between initiating and concluding eating. Not surprisingly, in most of these cases drivers drank while eating. Overall, there were 21 episodes in which another secondary task was observed between I1 and I2 or C1 and C2.

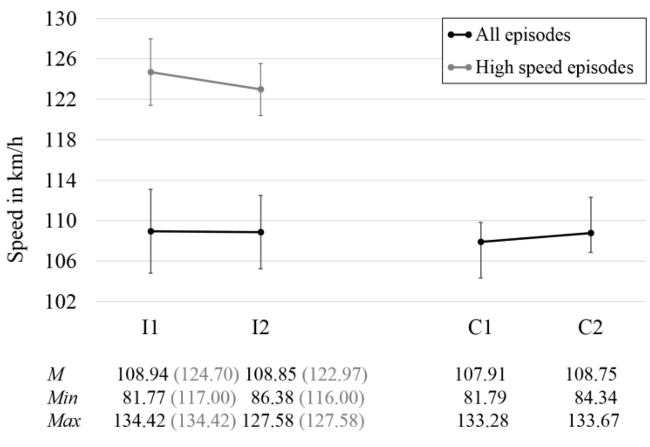
Figure 6: Duration of episodes for secondary task "eating".



The average speed at I1 and I2 as well as C1 and C2 is depicted in Figure 7. Speed differences between I1 and I2 varied from -8.84 km/h to 10.35 km/h. In 41% of all episodes, speed remained at approximately the same level. In 33% of the episodes, speed was reduced, while it was increased in 26%. On average, speed increased by 0.09 km/h between I1 and I2 ($t(38) = 0.123$, $p = .903$, $d = 0.01$). Again, a statistical analysis of the 25% of episodes with the highest speed at I1 (i.e., at or above 117.00 km/h) was inappropriate due to the low number of remaining episodes ($N = 10$). On a descriptive level, the data showed an average speed reduction of 1.73 km/h ($SD = 4.33$) between I1 and I2.

Between C1 and C2, speed differences varied from -11.57 km/h to 14.00 km/h. In 36% of the episodes, speed was increased by more than 1 km/h, while it remained at approximately the same level in 46% of the cases. A decrease in speed was observed for the remaining 18%. On average, this mean an increase in speed of 0.84 km/h ($SD = 4.13$), which was not statistically significant ($t(66) = -1.664$, $p = .101$, $d = -0.08$).

Figure 7: Speed at I1, I2, C1 and C2 for secondary task "eating".



Note. Error bars represent 95th confidence interval.

3.5 Adjusting/ monitoring radio or climate control

For adjusting/ monitoring radio or climate control we analyzed 94 episodes (among them 86 episodes of task initiation and 85 episodes of task conclusion) from 90 participants. The duration of secondary task engagement ranged from 2 s to 7 min (including interruptions) and 2 s to 4 min (time on task; see

Figure 8). On average, drivers engaged in the task for 37.39 s (*SD* = 57.09, including interruptions) and 29.30 s (*SD* = 45.43, time on task), respectively. Because of the rather short duration of this type of secondary task, there were no episodes in which another concurrent secondary task was performed in addition to adjusting/ monitoring the radio or climate control. Moreover, we found only 5 episodes in which another secondary task was performed between I1 and I2 or C1 and C2.

Figure 8: Duration of episodes for secondary task "adjusting/ monitoring radio or climate control episodes".

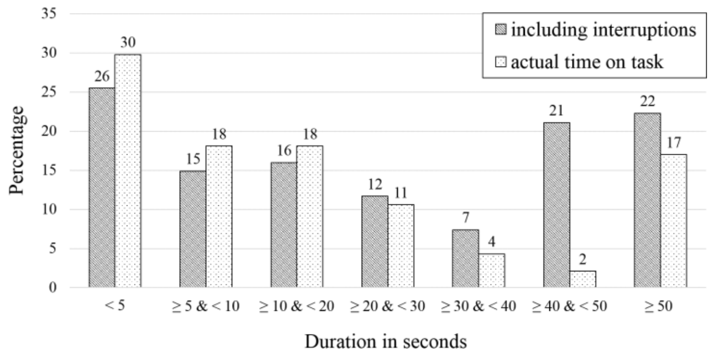


Figure 9 shows the average speed for the four points of measurement. The speed differences between I1 and I2 varied from -6.61 km/h to 12.00 km/h, with a mean increase in speed of 0.02 km/h ($t(85) = -0.040$, $p = .968$, $d = 0.00$). In 43% of the episodes, speed remained approximately at the same level, while it was reduced by more than 1 km/h in 30% and increased in 27% of the cases. With regard to the 25% of episodes with the highest initial speed (i.e., at or above 111.98 km/h), an average speed reduction of 1.03 km/h (*SD* = 2.79) from I1 to I2 was found. However, this speed reduction was not statistically significant ($t(20) = 1.689$, $p = .107$, $d = 0.21$, $N = 21$).

Speed differences from C1 to C2 varied between -12.00 km/h and 12.01 km/h, again with a statistically insignificant mean increase in speed of 0.17 km/h ($t(84) = -0.401$, $p = .690$, $d = -0.02$). In 36% of the episodes speed was increased by more than 1 km/h, remained at approximately the same level in 32% of all cases and was reduced by more than 1 km/h in the remaining 32%.

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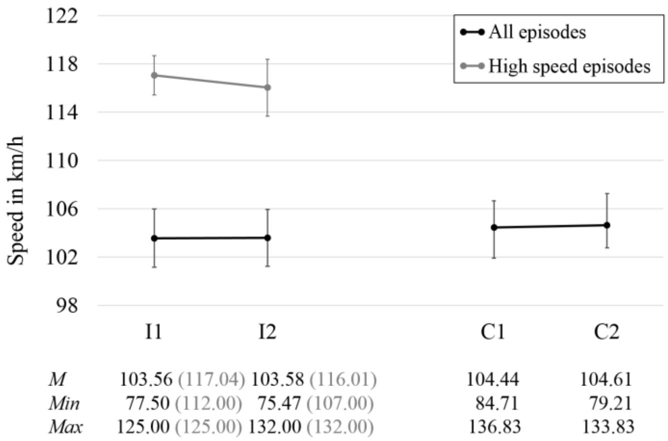
Figure 9: Speed at I1, I2, C1 and C2 for secondary task "adjusting/ monitoring radio or climate control".



Note. Error bars represent 95th confidence interval.

4 Discussion

4.1 Self-regulatory behavior

Aim of the analysis presented in this article was to study drivers' self-regulatory behavior during secondary task operation, focusing on drivers' speed selection on the interstate. The results provided some indication of self-regulatory behavioral adaptation in terms of speed adjustment while texting. While, on average, there was no significant reduction of speed at the beginning of a texting episode, there was a significant increase in speed after drivers had finished to text. More importantly, when focusing only on the episodes in which drivers were travelling at a rather high initial speed, a significant speed reduction was found comparable in magnitude to what has been reported from experimental studies on cell phone conversation (e.g., Haigney et al., 2000; Patten et al., 2004; Rakauskas et al., 2004) or text messaging (e.g., Yannis et al., 2014). This might be seen as evidence that when driving at higher speed, which can be considered to increase task difficulty, drivers tend to exhibit more self-regulatory behavior than when driving at lower speed (under otherwise comparable circumstances).

Not surprisingly, results of our analysis did not show any significant changes in drivers’ speed behavior when smoking, eating and adjusting or monitoring the radio or climate control. It seems that, at least under the circumstances that we analyzed, drivers had sufficient spare capacity to engage in additional simple manual secondary tasks and did not feel the need to adapt their speed.

In general, it should be noted that the effect sizes were rather small and behavioral patterns varied considerably between drivers. An explanation for that might be found in the sampling of the analyzed events. Our reliance on randomly selected episodes of driving has the potential to bias our sample towards frequent users, as, naturally, driving episodes from these participants will more often contain periods of secondary task engagement. Drivers who must be considered more experienced with secondary tasks while driving are more likely represented in the sample than drivers who rarely engage in secondary tasks. It can be assumed that due to habituation and practice, such frequent users do not or only rarely show self-regulatory behavioral adaptation at an operational level.

This issue is compounded by the focus on interstate driving in our analysis. Despite the relatively high speed levels, interstates are rather simple environments with a limited set of unpredictable events for which drivers need to be prepared. Thus, interstates might not elicit as much self-regulatory behavior as a more complex environment. In addition, the seemingly predictable nature of interstates make adaptation at a strategic level (i.e., the selection of a proper situation for secondary task engagement) much easier, which might even further reduce the need for a reduction of speed. As Tivesten and Dozza (2015) reported, drivers often initiate secondary tasks directly after completing high-demanding driving maneuvers, such as sharp turns or lane changes. The interstate as a driving context certainly supports such a task scheduling approach.

4.2 Challenges of using naturalistic driving data

It should be noted that our analysis is among the first to use naturalistic driving data to investigate drivers’ self-regulatory behavior in the wild. And, while our findings already show the potential of NDS in that regard, there is considerable room for improvements in the analysis approach.

One issue is our reliance on pre-identified episodes of secondary task engagement. Although we still were able to analyze a reasonable number of events, this number is only a small fraction of what the full dataset holds. It is certainly not feasible to completely review all the videos to identify secondary task episodes; however, it should be possible to develop smart sampling strategies that limit the number of videos to be reviewed while maximizing the chance to uncover secondary task episodes. For example, episodes of cell phone use might be identified through cell phone records (e.g., Cook, Antin, Atkins, & Hankey, 2015). Such strategies would allow for a higher level of control over the sample drawn (as compared to the random sampling) and, at the same time, have the potential to increase the number of episodes to analyze considerably.

The sample size is especially important as traffic conditions can vary substantially, which result in a lot of random noise in the data that might cover actual effects. Our approach to that problem was to focus on a rather controlled traffic context (i.e., interstates/ highways) and consistent traffic conditions (i.e., free flow driving). As a consequence, a lot of candidate episodes were discarded for analysis, leading to a reduction in the sample size. Others (e.g., Fitch et al., 2013; Tivesten & Dozza, 2015) have removed episodes in which the vehicles were more or less stationary, without additional filtering for, e.g., road type, presumably to avoid discarding too much data. Both approaches are not without issues. It might be argued that our strict requirements for inclusion might introduce certain biases, while the “lumping together” approach has the potential to dilute any effects due to the combination of vastly different situational contexts. Either way, a sufficiently large sample size can help to improve the validity of the resulting analysis.

An additional challenge arises from the fact that drivers often perform not just one secondary task while driving. Other secondary tasks, either concurrent tasks or tasks occurring immediately prior or after the task of interest, can complicate either the sampling (if they are filtered out) or the interpretation of the results (if they are left in the dataset). While in our analysis such cases were relatively rare and/ or of relatively short duration (e.g., a driver quickly adjusted the radio in addition to smoking), caution should be taken especially in cases in which the "additional" secondary task must be assumed to be more demanding than the task that is subject of the analysis.

The analysis of secondary task engagement is further complicated by the fact that in a lot of cases secondary task engagement is not an isolated singular event. Especially for a task like texting, we repeatedly saw multiple engagements in rather quick succession. It appeared, somewhat logically, that there were "conversations" taking place via text, with short breaks in between. These breaks would usually be indicative of the conclusion of a task, but, viewed as a whole, the succession of secondary task engagements might as well be considered one single task, at least from the perspective of self-regulation. If there indeed was some form of conversation going on, it might be reasonable to assume that the driver does not adapt speed with every single text message, but rather for the complete conversation. In the end, however, this is all a matter of interpretation and highly speculative, which makes the analysis (or filtering) of such episodes extremely difficult.

5 Conclusions

The present study analyzed drivers' self-regulatory behavioral adaptation in terms of speed adjustment while being engaged in different secondary tasks, using naturalistic driving data collected under the SHRP 2 research program. The results indicate that there is a small tendency among drivers to adjust speed while driving on the interstate when they engage in a demanding secondary task, such as texting, especially when initial speed is high. However, for other common secondary tasks no statistically relevant reductions in speed could be found. Even for texting, the practical impact of the found effects would be fairly limited. Nevertheless, this should not be seen as evidence that drivers do not adjust their behavior when engaging in secondary tasks. Instead, the results merely show that adjustment, under the circumstances studied, does hardly occur at an operational level. Considering previous research, it appears likely that drivers prefer to employ a strategic approach with regard to their decision when and when not to engage in a secondary task, rather than accommodate for the secondary task by changing their speed. The focus on behavioral adjustment at the operational level of driving, as often found in simulator studies and field experiments, is therefore not sufficient when trying to investigate drivers' self-regulatory behavior on free flow interstates.

The limitations of experimental approaches become even more apparent when considering naturalistic, uninstructed secondary task operation not only with regard to the "when", but also the "how". The vast variations that were observed in the way of how and for how long drivers engage in certain tasks show that the current scientific understanding of what, e.g., texting or eating while driving actually look like is still rather limited. Only naturalistic datasets seem to be able to provide such an understanding, which would be not only valuable in a strict scientific way, but could also proof useful with regard to the design of realistic reference tasks against which other secondary tasks could be evaluated.

Still, while naturalistic driving data might be the ultimate means to investigate what drivers do (e.g., adjust or not adjust their speed) and how they do it (e.g., position of cell phone while texting), it does not provide any information about *why* drivers act in a way they do. Other methods, such as focus groups, interviews or surveys, are better suited to investigate such specific aspects of driver behavior. It appears that, in order to obtain a comprehensive understanding about drivers' self-regulatory behavior, a mixed-method approach that includes, e.g., naturalistic setups as well as survey methods, but also experiments when suitable, is required. But the analysis of naturalistic driving data can and should play a vital role in such an approach, both to complement and validate results obtained through different means, as well as to generate new hypotheses to be tested in more controlled environments. The SHRP 2 dataset, which is still comparatively young and underexplored, might be the perfect tool to do this.

Appendix A

Table 4: Calculation for separate analysis conditions.

Secondary task category	Calculation for all episodes	Calculation without episodes with duration ≤ 20 s	Calculation without repeated episodes of the same driver
Texting			
Initiation	I1-I2 (*SD*) = 0.46 (5.21)	I1-I2 (*SD*) = 0.55 (5.20)	I1-I2 (*SD*) = 0.49 (5.88)

	t(154) = 1.105 p = .271 d = 0.04	t(132) = 1.222 p = .224 d = 0.05	t(79) = 0.746 p = .458 d = 0.04
Conclusion	C1-C2 (*SD*) = -1.10 (4.94) t(158) = -2.813 p = .006 d = -0.10	C1-C2 (*SD*) = -1.08 (4.81) t(135) = -2.614 p = .010 d = -0.10	C1-C2 (*SD*) = -1.50 (5.58) t(72) = -2.302 p = .024 d = -0.12
Smoking			
Initiation	I1-I2 (*SD*) = -0.91 (3.02) t(21) = -1.423 p = .170 d = -0.07	I1-I2 (*SD*) = -0.91 (3.02) t(21) = -1.423 p = .170 d = -0.07	I1-I2 (*SD*) = -0.98 (3.37) t(14) = -1.122 p = .281 d = -0.08
Conclusion	C1-C2 (*SD*) = -0.98 (4.31) t(31) = -1.284 p = .209 d = -0.07	C1-C2 (*SD*) = -0.98 (4.31) t(31) = -1.284 p = .209 d = -0.07	C1-C2 (*SD*) = -1.38 (5.04) t(18) = -1.194 p = .248 d = -0.10
Eating			
Initiation	I1-I2 (*SD*) = 0.09 (4.76) t(38) = 0.123 p = .903 d = 0.01	I1-I2 (*SD*) = -0.98 (4.31) t(38) = 0.123 p = .903 d = 0.01	I1-I2 (*SD*) = t(36) = -0.153 p = .879 d = -0.01
Conclusion	C1-C2 (*SD*) = -0.84 (4.13) t(66) = -1.664 p = .101 d = -0.08	C1-C2 (*SD*) = -0.84 (4.13) t(66) = -1.664 p = .101 d = -0.08	C1-C2 (*SD*) = -0.61 (3.96) t(59) = -1.199 p = .235 d = -0.06
Adjusting/ monitoring radio or climate control			
Initiation	I1-I2 (*SD*) = -0.01 (3.41) t(85) = -0.040 p = .968 d = 0.00	I1-I2 (*SD*) = -0.33 (4.00) t(36) = -0.505 p = .617 d = -0.03	I1-I2 (*SD*) = 0.10 (3.35) t(79) = 0.274 p = .787 d = 0.01
Conclusion	C1-C2 (*SD*) = -0.17 (3.94) t(84) = -0.401 p = .690 d = -0.02	C1-C2 (*SD*) = -0.03 (3.18) t(35) = -0.061 p = .952 d = 0.00	C1-C2 (*SD*) = -0.10 (3.89) t(76) = -0.230 p = .819 d = -0.01

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