Naturalistic driving study on the usage of smart phone applications while driving

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Abstract:
We present the first results from a study that tracked how Finnish drivers use their smart phones while driving. We monitored 30 heavy-user drivers in Finland in June-September 2016, and recorded the times when they used their phones, the application used at the time of touch, and the location and speed of the car. Touches were used as a proxy for estimating visual distraction due to visual-manual tasks. Our data set allows us to determine whether drivers use their phones differently on different road types (highway, main road, local rural road, urban road). We found that the road type has very little effect on phone use. The drivers produced more touches per hour on urban roads but the instances of use tend to be slightly shorter than on the highway or on main roads. We also collected statistics on the applications that were used. By far the largest amount of distraction is caused by the WhatsApp messaging service, used by a majority of the drivers. An instance of WhatsApp use included a median of 12 touches, and had a median duration of 35 seconds. By contrast, navigation applications (better optimized for on-road-use) included a median of 4 touches and lasted 11 seconds. This suggests that the greatest risk from smart phone use may be currently caused by messaging applications.

1. Introduction

Although it is well known that many drivers use their smartphones to do various tasks while driving (e.g., [7][15]), little to nothing is known about the actual applications they use or the exact traffic conditions in which they use those applications. This information is important for determining the actual risk level caused by the distraction. A given application, such as texting, may cause a very serious risk of accident on a busy and congested urban road. The risk may be considerably smaller when driving along a straight and nearly empty highway.

In this paper, we present findings from naturalistic driving data that enabled us to determine what applications drivers use, whether drivers use different applications in different driving scenarios, and whether they use applications differently in different driving scenarios. Ideally, we would be able to compare what applications are used on highways, major roads, minor roads, and urban traffic. The greatest limitation is that no data on the congestion or real-time traffic density is available. However, the road type gives us at least a rough indication of the visual demands of the driving scenario [8].

Although there is no exact way to determine the visual-manual distraction caused by any given application, we used the number of touches on the smart phone as a proxy. A touch on a touch screen is almost always accompanied by a glance on the touch screen due to the limited haptic feedback of the device [2][14].

Among others, Victor et al. [15] have shown that a series of glances away from the road may lead to safety-critical uncertainty of the task-relevant road events, even if the glances off road were brief. Therefore, an application that requires a large number of touches in a short time period can be considered to cause high cognitive demand on the driver. On the other hand, an instance of use, of which duration is long, means that the driver is distracted for a longer time period. Longer in-car tasks have been associated with increased probability of increased individual glance durations off road [10][11].

There is evidence from naturalistic driving (e.g. [16]) as well as from on-road (e.g. [17]) and simulator studies (e.g. [12]) suggesting that drivers adapt their off-road glancing behaviours according to the demands of the driving task. Drivers tend to decrease their off-road glance durations and the number of off-road glances when the demands of the driving task increase. The naturalistic field study of Metz et al. [13] (maneuvering, German drivers) and the video-clip based study of Hancox et al. [4] also suggest that drivers tend to attend to distracting activities in a situationally aware manner.

Based on the previous research findings, our preliminary hypothesis was that at least experienced drivers should have developed a sense of acceptable risk levels, and would be able to adapt their smart phone usage to the demands of the given driving conditions. We would thus expect to see differences in smart phone use between road types. In particular, we hypothesized that there would be less touches on the phone and the most demanding applications would be used less often in high-demand driving scenarios. It was our expectation that urban roads would present the need for most vigilance due to intersections, traffic lights and other traffic (including cars, bicycles and pedestrians), and hence we would see less phone use in urban conditions than on highway or main roads, even though the highways and main roads have higher speeds.

2. Method

2.1 Hardware and Software

The results presented here are a subset of a larger on-going experiment, studying the effects of distraction warnings on smart phone use while driving. The data are from the control part of the experiments, when usage data was simply collected. The control phase was finished by September 2016, but the experimental phase continued until December 2016, ending to a web questionnaire. More results will be described in later papers.

The data were collected using custom software developed by Ficonic Solutions Ltd, located in Jyväskylä, Finland. The software consisted of two parts: a “Watcher” software running on Samsung XCover 3 smart phones that were installed in the volunteers’s cars dashboards, and a small “Observer” package that was installed on all Android phones and other Android devices which the drivers might have used while driving. The Watcher software created a Wifi hotspot, onto which the Observer phones connected when within range.

The Watcher phones had a continuous cellular network connection to allow enhanced GPS positioning. Data were uploaded to the remote server whenever the phone was on standby via 3G or 4G connection, depending on the connectivity at the area. The Watcher software recorded the GPS position at one-second intervals whenever the car was in motion. The in-built power-savings system in the Android version meant that whenever the car was stationary, no GPS positions were recorded.

In order to enable the location-based warnings in the second phase, the Watcher software constantly mapped the position of the car against the Finnish national Digiroad map data set (http://www.liikennevirasto.fi/web/en/open-data/digiroad), and determined the road on which the car was for any given GPS fix.

The Observer background software in the drivers’ Android devices worked by creating a transparent layer over the other applications. A touch on the phone was thus recorded by the Observer software. A flag about every touch was immediately sent over the WiFi network to the Watcher phone, including information about the Android front application (FrontApp) that was running at the moment.

2.2 Participants

The number of volunteers recruited in the study was initially 31, starting in June 2016. One test subject dropped out of the study before sufficient control data could be collected. The total number of drivers in this study is therefore N=30 (22 M, 8 F; median age 37, mean age 39, SD 12.2, range 18-64). Participants were recruited via ads in newspapers and social media. The recruitment ad required volunteers to drive "a lot" and to "regularly" use their mobile phones while driving, but no quantitative criteria were given. Well over 200 applications were eventually received. The final participants were selected based on multiple criteria, including how much they reported themselves to drive per year. Those drivers were favored who reported driving in both urban and rural areas. An attempt was made to choose as many women as possible, and to achieve a wide spread in ages. The participants got to keep the Android smart phone, car charger and the car holder as a reward for participation. All the participants signed a written informed consent document prior to participation and they were allowed to withdraw from the study at any point. The University of Jyväskylä Ethical Committee was enquired for the need to have an ethical review for the study and it was approved without a formal review.

2.3 Data Collection and Analysis

The initially planned number of days for the drivers to spend in the control stage was 63 days. However, this was increased to 84 days (12 weeks) for the great majority of the drivers. In practice, there was a large variation in the number of days that drivers actually drove during the control period, enhanced by technical problems, which caused periods of data blackout. The mean number of days was 43.6 (SD 19.9), with median 50.5 and range from 11 to 81.

The data used in this paper are only for cases where the car was traveling with a speed of at least 2 m/s (7.2 kmh). This was the lower speed limit that could be reliably detected by the GPS. Data were collected separately in cases where the car was stationary, but this data is not included in this paper. In general, there was no significant difference between the number of touches while driving or while stationary (p = .806). The number of hours spent driving varied from 10 to 167 hours, with a median of 50 hours (mean 57 hours). The total number of touches recorded per driver also varied enormously. The range was 254 to 25439, with three drivers recording over 10,000 touches during the control period. The median for touches was 1817. The distributions of the data were mostly non-Gaussian and therefore, nonparametric tests were utilized for testing the hypotheses. Where applicable, Cohen's d is reported as a measure of effect size.

2.4 Known Limitations

There are some caveats to the touch data. Due to technical properties of the Android phones, the front application cannot always be identified accurately. Also, some applications with a "floating user interface" (such as Facebook Messenger) are not captured at all. Touches related to the phone keylock are missed completely. The numbers presented here are therefore lower limits. However, we estimate that the error is small (0-6 touches per instance of use, that is, 19% of touches on average, if assuming the phone keylock was activated between each instance of use).

3. Results

3.1 Overall Statistics

The mean touches per hour for each driver can be calculated by calculating the number of touches where the speed is at least 2 m/s, and dividing by the number of GPS locations recorded for the driver with speed at least 2 m/s. Since GPS locations are recorded once a second, this ratio can be multiplied by 3600 to give touches per hour. The distribution is highly skewed (Figure 1), with two drivers averaging over 400 touches per hour. The median number of touches is 43, meaning less than one touch per minute. The 15th and 85th percentiles are 14 and 131 touches, respectively, and the range is 5 to 475.

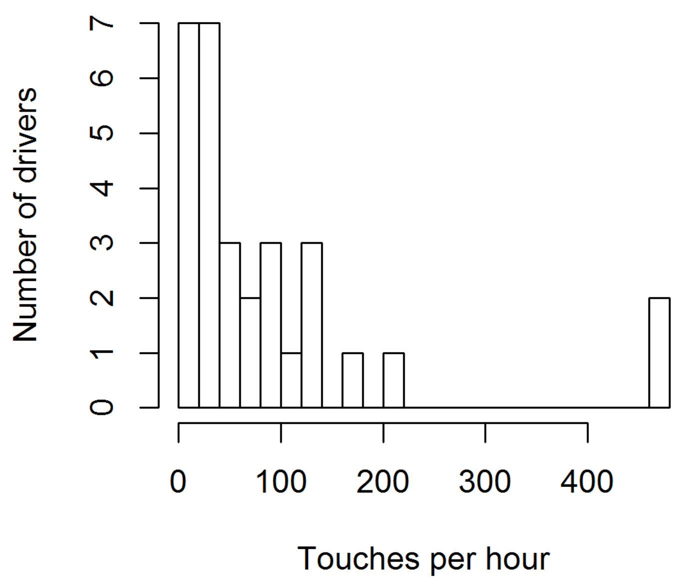

Fig. 1. *Touches per hour for the 30 drivers.*

3.2 Analysis per Road Type

Four classes of road can be identified from the data:

1. Highway (default 120 kmh, sometimes 100 kmh). No opposing traffic.
2. Main rural road (default 80 kmh, sometimes 60 kmh [at some crossroads] or 100 kmh). By default the driver has right-of-way.
3. Local rural road (speed limit varies, default either 80 kmh or 50 kmh). Driver may or may not have right-of-way.
4. Urban road (default 40 or 50 kmh, sometimes 30 kmh).

Statistics for a given road type were compiled only when there were at least 50 touches by a driver for a given road type. The number of touches in in each road can be normalized to the amount of time spent on the given road type. Whenever the car is in motion, the location is updated once a second. Touches per hour can thus be estimated by dividing the number of touches by the number of location fixes and multiplying by 3600. The results are shown in Figure 2.

As implied by Figure 2, the touches per hour are very strongly non-Gaussian. For the highway data, the Shapiro-Wilks test gives W=0.62, which implies non-normality with p<0.01. The Wilcoxon rank sum test shows no statistically significant differences between the means for the various road types; the highway versus local has p=0.21, while the rest are much higher (Table 1).

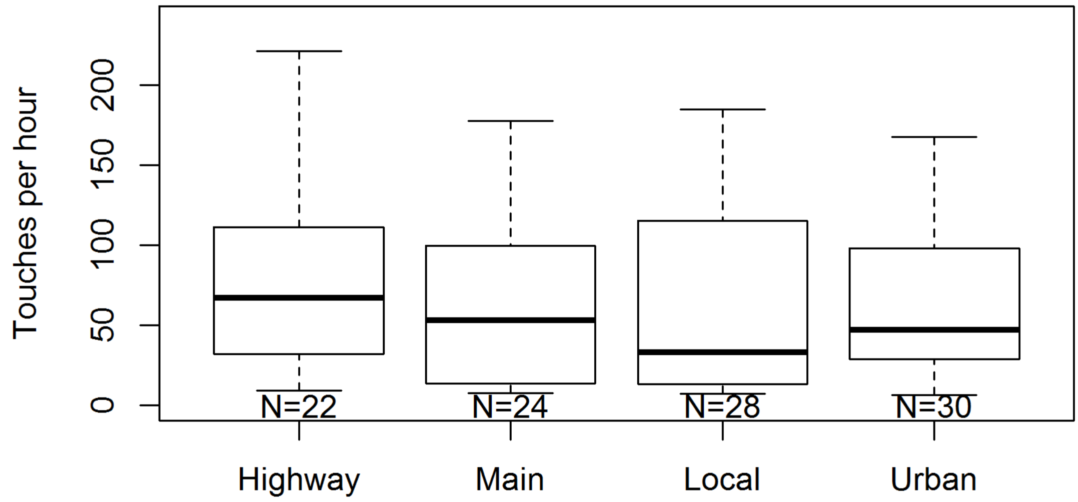

Fig. 2. *Boxplot of touches per hour by the four different road types (data was included only if the driver had at least 50 touches on the given road type).*

Table 1 Touches per hour on the different road types

Road type	Touches per hour, median	15th percentile	85th percentile
Highway	67	21	170
Main	53	12	130
Local	33	9	142
Urban	46	142	157

Within-subject variations were estimated by dividing each driver's touch density by the driver's mean touch density over the whole experiment (Figure 3, Table 2). Wilcoxon rank sum tests (Table 3) show that the mean of the urban tracks is larger than the other road types, the effect size being medium. Thus, drivers tended to touch their phones more while driving on urban roads.

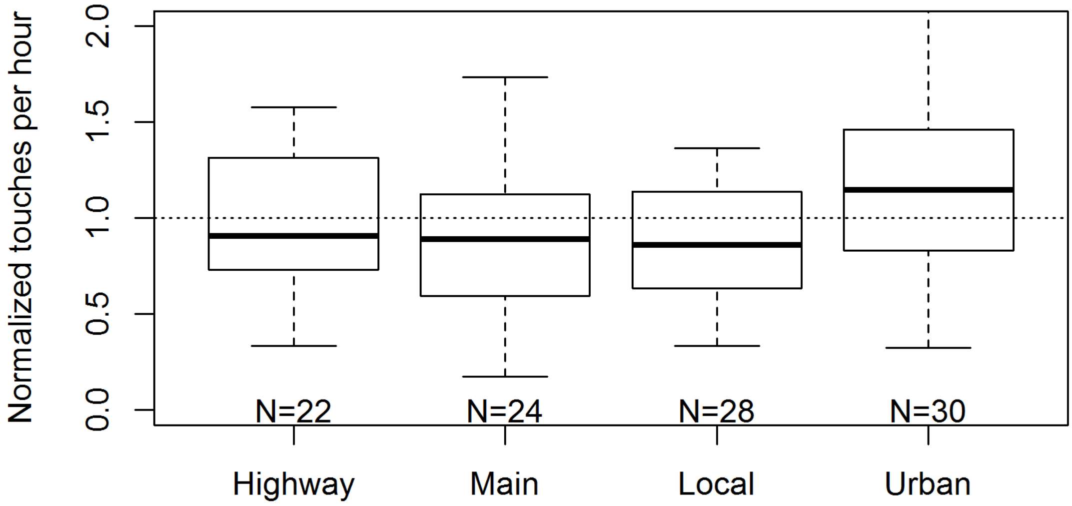

Fig. 3. *Normalized touches per hour by road type.*

Table 2 Normalized touches per hour on the different road types

Road type	Norm touches per hour, median	15th percentile	85th percentile
Highway	0.91	0.65	1.37
Main	0.89	0.51	1.49
Local	0.86	0.62	1.19
Urban	1.15	0.67	1.66

Table 3. Results of Wilcoxon rank sum tests for normalized touches per hour

Road type	Main	Local	Urban
Highway	p=0.47	p=0.40	p=0.106 (d=0.51)
Main		p=0.92	p=0.014* (d=0.72)
Local			p=0.016* (d=0.65)

**Significant at p<0.05. Cohen's d is calculated for the statistically significant cases.*

3.3 Vehicle Speed at Touch

In order to analyze the reliability of our classification system, we analyzed the vehicle speeds at touch on the different road types. The mean speed at touch depends on the road type, as seen in Figure 4. The mean speed (SD) for highway touches is 101 (11) kmh, main road 80 (7), local 60 (11), and urban 34 (12) kmh. These are very close to the nominal maximum speeds allowed on these road types. The finding gives support for our road classification system.

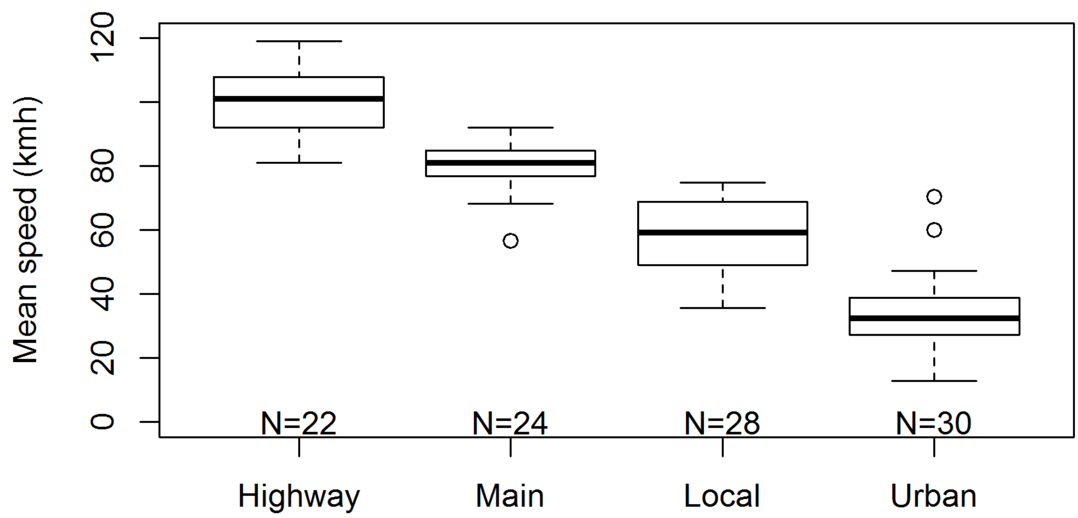

Fig. 4. *Mean speed at touch by road type.*

3.4 Analysis of Application Use Instances

Identifying an application use instance is not trivial with this data set. The FrontApp code returns only one application name, which sometimes can be tied to a specific application but sometimes cannot. Different FrontApp names may be returned at different parts of the application instances, while some FrontApp names may be related to a large number of applications. Depending on the model and Android version of the driver's phone, the FrontApp might not be identified at all (returning a blank, or NA). The ratio of unidentifiable FrontApps ranged from about 3% to almost 30% for different drivers.

We defined application use instances by clustering the touches. If two touches are separated by less than 30 seconds, they are considered to be part of the same cluster. The 30-second threshold is based on the on-road data of Blanco et al. [1], in which the longest and most complicated in-car tasks lasted for 30 seconds on average, and the naturalistic driving data of Christoph and van Nes [3], in which the average duration of manual interactions with a mobile phone was 31.0 seconds. The most frequently occurring FrontApp tag in the cluster is considered to be the main application used in the cluster.

Especially on urban roads, drivers may perform part of the task while stationary or braking to stationary. In this analysis, we have included only instances, which start when the car is moving with a speed of at least 2 m/s during at least one touch. The data are normalized to uses per hour by the same method used to derive touches per hour (Figure 5).

The data are again non-Gaussian, with a Shapiro-Wilkes test for the highway data giving W=0.91, implying non-normality with p=0.043. Non-parametric tests thus need to be performed again. The median is 16.5 and 15-85 percentile limits are 11 and 29. A typical driver in out data set thus uses some application every four minutes or so, while the heaviest users are using their phones essentially almost constantly. The different road types have no significant differences in application use instances per hour (p=0.12, Figure 6 and Table 2).

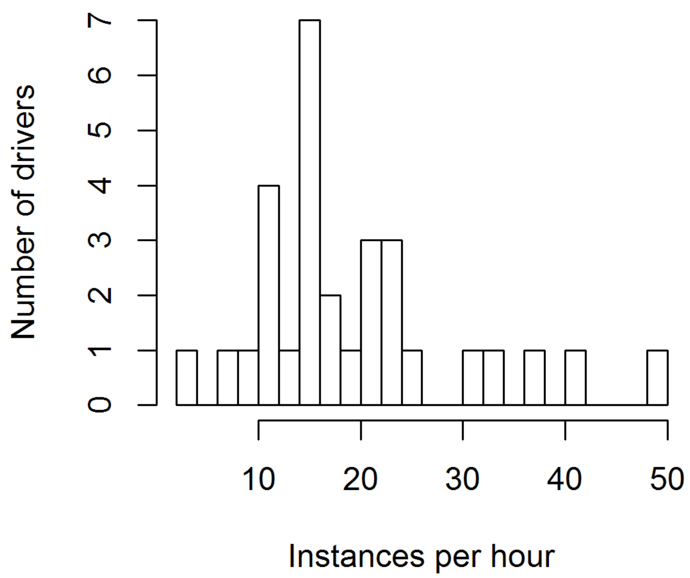

Fig. 5. *Application use instances per hour, N=30.*

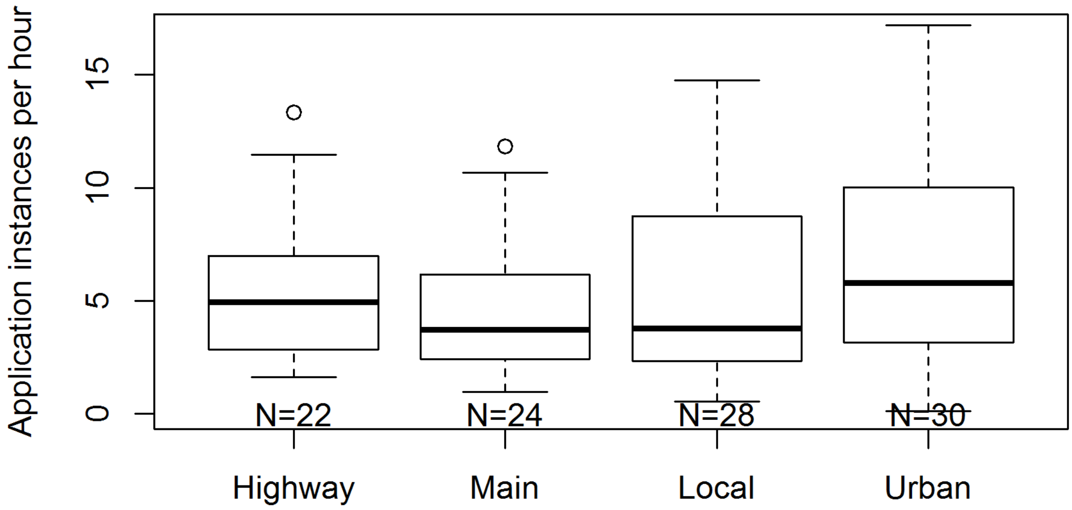

Fig. 6. *Application use instances per hour by road type.*

Table 4 Application use instances per hour on the different road types

Road type	Application use instances per hour, median	15th percentile	85th percentile
Highway	4.9	2.7	8.9
Main	4.0	1.7	7.7
Local	3.8	2.0	11.2
Urban	5.5	2.4	11.9

The duration of each application use instance can also be estimated (time between first and last touches in cluster). In this case, there actually are statistically significant differences between the road types (Figure 7 and Table 5). According to the Shapiro-Wilks test, the data are too skewed to make an ANOVA comparison. However, a Wilcoxon rank test (Table 6) shows that task durations are significantly longer on highways and main roads than on urban roads. The effect size is small (Cohen's $d < 0.50$). Application use instance durations tended to be shorter on urban roads than on other road types.

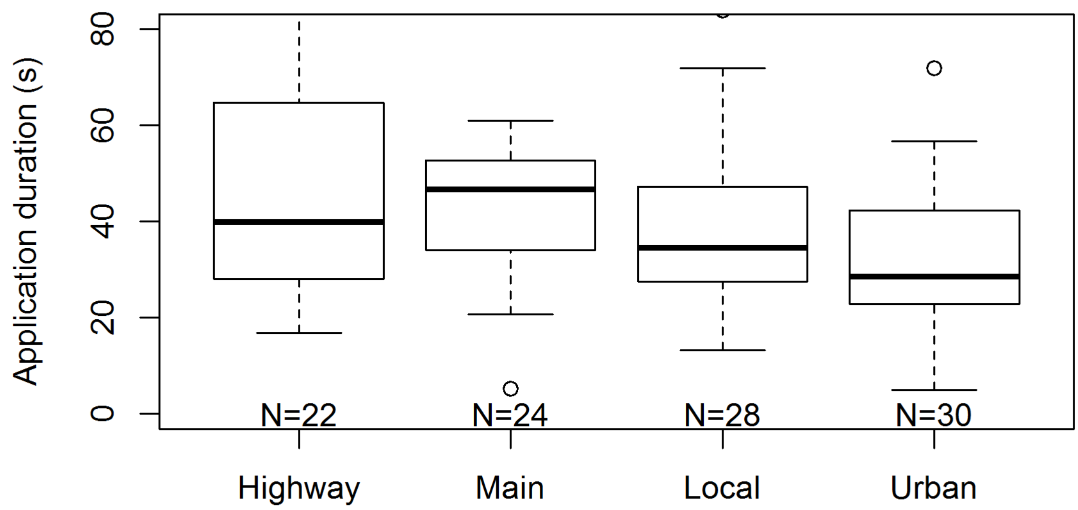

Fig. 7. *Mean duration of application use instances by road type.*

Table 5 Duration of application use instances on the different road types

Road type	Median duration, sec	15th percentile	85th percentile
Highway	40.0	27.9	79.6
Main	46.7	29.0	59.8
Local	34.6	25.6	52.3
Urban	28.6	21.1	47.8

Table 6. Results of Wilcoxon rank tests for mean duration of application use instances

Road type	Main	Local	Urban
Highway	*p*=0.64	*p*=0.33	*p*=0.03* (*d*=0.45)
Main		*p*=0.13	*p*=0.02* (*d*=0.40)
Local			*p*=0.18

**Significant at p<0.05. Cohen's d is calculated for the statistically significant cases*

3.5 Frequently Used Applications: General Statistics

The application analysis is complicated somewhat by the fact that on different Android phone models, the FrontApp listed may be different for the same application, or in some cases the same for different applications. For example, Spotify use can be marked by at least three different FrontApp values.

The actual number of application use instances per application per user is also relatively small. Thus, it is not possible to make reliable comparisons between different drivers or road types. However, accurate aggregate statistics can be collected, that is, combined statistics from all users over the entire control period (see Table 7).

The most used applications were also used at all speeds. PokémonGo was an exception; it was played mostly at lower speeds, as could be expected from the game mechanics. The median speed during an instance of PokémonGo usage is just 21.8 kmh; that is, it was very often played at crawling speeds. However, there are also some instances of use at higher speeds (19 above 60 kmh). By contrast, for instance WhatsApp was used almost evenly at all speeds (median 58.1 kmh). All of the frequently used downloadable applications are also among the 100 most downloaded applications in Google Play in Finland, which suggests the applications drivers use in the car are the same applications they use in general. However, naturally the frequency of use for driving-related applications, such as navigation applications, could be higher than outside the car.

Table 7 Statistics for the most frequently used applications

Application	N instances	Touches/instance median (15%-85%)	Duration sec median (15%-85%)	Speed kmh median (15%-85%)	N drivers using
Contacts	811	6 (3-21)	17 (4-57)	56 (23-93)	27
Whatsapp	614	12 (4-86)	35 (9-112)	58 (21-95)	23
Music	356	6 (3-20)	17 (3-48)	69 (30-92)	12
Maps	284	4 (1-20)	11 (1-42)	60 (18-95)	19
Facebook	210	10 (1-45)	31 (10-96)	71 (22-99)	17
PokémonGo	172	27 (7-146)	141 (29-651)	22 (10-49)	4
Search	163	14 (5-47)	34 (12-83)	55 (11-95)	11
Dialer	116	6 (3-23)	19 (4-65)	55 (17-100)	12
Browser	109	9 (3-31)	36 (5-89)	66 (28-94)	17
MMS	94	9 (4-46)	29 (7-97)	49 (20-93)	14
YouTube	64	10 (2-64)	24 (2-83)	82 (27-89)	4
Email	60	12 (5-52)	45 (14-129)	73 (24-109)	16
Banking	46	9 (3-27)	28 (6-64)	56 (19-94)	12
Email	42	12 (5-50)	45 (13-130)	73 (24-109)	9
Netflix	33	3 (1-12)	10 (1-41)	84 (59-86)	3
Calendar	31	12 (6-44)	39 (20-134)	61 (8-84)	12
Instagram	24	10 (4-75)	34 (7-128)	73 (31-100)	6
Camera	19	7 (3-45)	31 (3-69)	52 (21-96)	12
Snapchat	18	14 (4-27)	26 (7-47)	42 (29-60)	2
Gallery	17	8 (3-39)	29 (5-151)	42 (25-68)	6
Fonecta*	16	10 (5-26)	30 (9-109)	61 (18-86)	5
News	10	9 (4-17)	16 (1-52)	54 (19-118)	3
Outlook	7	8 (5-30)	37 (29-117)	88 (80-99)	2
Twitter	7	17 (8-157)	75 (25-320)	79 (33-98)	2
Tinder	5	22 (6-34)	37 (25-70)	49 (41-81)	3

**Fonecta is a commonly used Finnish directory service*

4. Discussion

Our main research question is whether we can observe any statistically significant differences between phone use on the different road types. Our data suggest that drivers modulate their phone use behavior depending on road type. The probability of initiating an application does not vary significantly between road types, although the probability is slightly higher for urban roads (p=0.11). However, drivers produce significantly more touches per hour on urban roads (medium effect size), while the time duration spent on any given application instance is shorter on urban roads (small effect size).

The effect is in fact in the opposite direction to our preliminary hypothesis. Urban roads present the most visually demanding driving scenario, and we would have expected to see a decrease in phone usage. The driving speeds are significantly lower in urban roads than on highway or main roads but the density of crossing traffic in the form of cars, cyclists and pedestrians is significantly higher on the urban roads (at least in Finland). As indicated in [8], highway road environment with no crossing traffic should present the least visual demand, and thus we expected to see more touches and application use on highways and main roads than on urban roads. A similar opposite finding was made by Huth et al. [6] in a smaller naturalistic study (N=9) in France, suggesting that the drivers used their phones more in urban road environments than on highway or rural roads.

The experiment by Horrey and Lesch [5] indicated that although their drivers seemed to be aware of the demands of the driving situation ahead, the drivers did not tend to postpone the presented secondary tasks even if they were given the chance. One explanation for these types of behaviors, similar to our findings, could be the impairment of situation awareness due to the cognitive demands of the secondary in-car tasks [18].

The lack of information about the real-time traffic conditions makes an exact analysis difficult at the moment. For further studies, it will be interesting to analyze the data by road type and time of day as a proxy of traffic densities. Also, our definition of "application use instance" becomes problematic in urban traffic, where stops may be frequent. The more frequent stops on the urban roads may encourage the use of the smart phone. At a general level, there were as many touches on the smart phone made while driving as while stationary.

Contacts and WhatsApp were the most commonly used individual applications. The touch and duration data for those two applications were however quite different. A WhatsApp interaction included a median of 12 touches and lasted for 35 seconds; a Contacts interaction included a median of 6 touches and just 17 seconds. We can assume that the number of touches and duration of instance are related to the risk caused by the distraction.

This suggests that not all applications are equally risky. A good example of a relatively safe application is Maps, where a typical interaction required just 4 touches and 11 seconds. The design of navigation applications (at least implicitly) takes into account the fact that drivers use them while driving, and hence visual-manual interactions are often minimized. However, one should realize the apparent usability paradox here; making an application more easily (and safely) usable while driving may encourage and increase the frequency of use, which may again increase the overall risk of distraction.

Possibly our most surprising finding was that four drivers used PokémonGo so heavily that the application rose to be seventh on the most frequently used applications list (by the total number of touches). Furthermore, the interactions during this application were particularly long (median 141 seconds with 27 touches). The result implies that a high risk level is accepted by some of our heavy users. The application was mainly used at low speeds but this may be due more to the game mechanics (targeting) instead of risk-related adaptive behaviors.

All our participants were drivers who drive a lot and admit to use their smart phones frequently while driving. The findings may not represent the behaviours of drivers who drive less frequently or use their smart phones while driving less frequently. In addition, the drivers were Finnish and there may be cultural differences in multitasking behaviours behind the wheel [19]. The Finnish road system is fairly simple and there are much less road users per kilometre than, for instance, in the United States or in China. Similar studies in different cultures are needed.

For future analyses, the location data could be examined in greater detail for finding possible patterns on which kind of locations people tend to use their phones while driving. Furthermore, acceleration data could be examined for the relationships between touches and vehicle speed state as well as lateral movements.

Another limitation of our study was the absence of eye tracking. We were not able to analyse if the drivers modulated their in-car glance durations based on the demands of the traffic scenario, as suggested by [12], [16] and [17]. For the phone use instances and the number of touches the evidence is, however, clear; our drivers did not adapt their behaviour according to the demands of the road environment but even an opposite effect was found. This finding suggests that context-sensitive distraction warnings (e.g., [9]), which were studied in the larger experiment, could be useful, if effective, in making drivers to better adapt their phone usage according to the demands of the driving situation.

5. Conclusions

The phone use of 30 car drivers was monitored in June-September 2016 in Finland. All of the drivers were volunteers who admitted to using their mobile phones frequently while driving. There are large variations between drivers. Touches per hour could be unambiguously determined; the median value was 43 touches per hour (15th percentile 14, 85th percentile 131). The number of application instances per hour could be determined from the touches; the median value was 16.5 (15th percentile 11, 85th percentile 29). Since the drivers were not selected from a random sample, these figures cannot be generalized to the general population.

The data showed an unexpected tendency in phone use: drivers tended to make more touches per hour on urban roads than on other road types. A small but statistically significant difference was seen see in the time duration spent on individual applications: on highways the median duration of an application use instance was 40 seconds, while on urban roads the median was 28.6 seconds.

The applications used by the drivers could be identified, though with some caveats. The two single most used application, by a rather large margin, were Contacts and the WhatsApp messaging software. One instance of WhatsApp also required a large number of touches (median 12). By contrast, Contacts required only 6 touches. Another commonly used application, Maps, required only a median of 4 touches per use instance. This suggests that not all applications are equally risky in terms of distraction. A surprising find was that PokémonGo was one of the most heavily used applications in traffic (a small minority of drivers using it very heavily).

The findings indicate, unexpectedly, that Finnish drivers who use their smart phones while on the move use their phones more frequently while driving in urban conditions. The usage pattern may however be slightly different, with application uses being performed more rapidly in the urban conditions.

Acknowledgments

We thank Ficonic Solutions Oy of Jyväskylä, Finland, for designing the software used in this experiment. This work was supported by the VisGuard project, funded by TEKES (Finnish Funding Agency for Technology and Innovation; Grant TEKES Dnro 813/31/2015) and the University of Jyväskylä.

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