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Is organized carpooling safer? Speeding and distracted driving behaviors from a naturalistic driving study in Brazil

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ABSTRACT

Carpooling consists of drivers and passengers sharing a journey and its costs. Nowadays, in the context of mobility as a service, organized carpooling encompasses a service and trust relationship between drivers and passengers, by matching common routes and splitting cost through mobile phone applications. Therefore, passengers expect a certain level of travel quality and safety. In this context, this research aims to verify the hypothesis that drivers in an organized carpooling situation (CP) show safer driving behavior in terms of speeding (SP) and mobile phone use while driving (MPU) in comparison with non-carpooling (NCP) drivers. The research is based on data from the Brazilian Naturalistic Driving Study (NDS-BR) conducted in the City of Curitiba, with 40.45 driving hours and a traveled distance of 895.87 km. Methodology included the selection of safety performance indicators on SP and MPU, use of nonparametric Wilcoxon signed rank test for safety performance indicator comparisons and Pearson Chi-Square to test the association between CP or NCP and low or high indicator values. Hypothesis test results point in the same direction and partially confirm the initial assumption that CP induces safer behavior in terms of speeding. The statistically sound results showed that CP drivers engaged in less speeding episodes and mobile phone use duration in comparison to NCP drivers, as well as lower speed while using a mobile phone. In addition, driver behavior in CP and NCP situations also differed in terms of the type of MPU, with the proportion of types of use that demand a higher level of visual and manual distraction being higher among NCP drivers. In summary, these results confirm the initial hypothesis of safer driving behavior during carpooling in terms of MPU while driving.

1. Introduction

Organized carpooling or ridesharing is a form of sharing the use of the private car on routes that are entirely or partially common between a driver and at least one other passenger in the vehicle, whose matching and cost sharing are promoted by an operating agency (Furuhata et al., 2013). Currently, in the context of mobility as a service, a series of applications that facilitate the matching between those who are willing to offer a ride and those looking for a ride are available on the market. These applications incorporate cost estimation and splitting tools, as well as enabling the payment for the trip by the passenger. Studies indicate benefits of carpooling practice such as a reduction in congestion rates and pollutant emissions, due to the increase in vehicle occupancy, in addition to direct user benefits related to the reduction in the cost of travel, and reduction of individual commuting (Bellemans et al., 2012; Galland et al., 2014; Wright et al., 2020).

In the road safety field, some studies based on the observation of the real driving task – naturalistic driving studies (NDS) – which controlled the presence of passengers indicated a lower incidence of mobile phone use while driving (MPU) when there is a passenger (Metz et al., 2014; Tivesten and Dozza, 2015; Christoph et al., 2019). However, research based on the Australian Naturalistic Driving Study (ANDS), which

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considered a variety of secondary tasks, found a higher engagement rate in secondary task per minute for drivers accompanied by passengers (Young et al., 2019). It has been suggested that the differences on MPU across studies may be explained by the idea that drivers tend to avoid higher risk secondary tasks (such as the MPU) in the presence of passengers more than minor risky tasks such as adjusting a vehicle device, singing or talking to yourself, looking at an object / event outside the vehicle, or simply looking at objects inside the vehicle.

Previous research has consistently shown that conversing on a mobile phone is riskier than conversing with passengers (Hunton and Rose, 2005; Drews et al., 2008). In addition, an Israeli study based on observing behavior from locations outside the vehicle identified a higher frequency of manual tasks with the mobile phone among unaccompanied drivers (Rosenbloom and Perlman, 2016). This is largely explained because the passengers also have an understanding of the driving demands and self-regulate their engagement or may share demands with the driver (Oviedo-Trespalacios et al., 2016).

Regarding speeding behavior, the results of survey data show that the presence of a passenger may influence both the avoidance and encouragement of speeding, depending on factors such as gender and age of both driver and passenger (Regan and Mitsopoulos, 2001; Conner et al., 2003; Fleiter et al., 2010). Data from the SHRP 2 (Second Strategic Highway Research Program Naturalistic Driving Study) project indicate that the presence of the passenger tends to have a greater influence in terms of positive safety attitudes on those behaviors at higher risk (Precht et al., 2017). Although the literature has a reasonable number of NDSs that address speeding (NHTSA, 2012, 2013; Richard et al., 2013, 2017; Ellison and Greaves, 2015; Ghasemzadeh and Ahmed, 2019; Yu et al., 2019), we identified few studies investigating speeding considering the presence / absence of passenger, apart from those dealing with peer influence – a distinctly different context in comparison with organized carpooling (Scott-Parker et al., 2009; Simons-Morton et al., 2011, 2012). To the best of our knowledge, it appears there has been no previous NDS analyzing the behavior of drivers during organized carpooling.

This differentiation between a regular trip and organized carpooling is important, since inherent in organized carpooling is a relationship of trust in the service provision arrangement (Galland et al., 2014; Amirkiaee and Evangelopoulos, 2018). Indeed, carpooling presupposes a standard of quality and safety. In organized carpooling, there is also an opportunity for passengers to evaluate their driver, so that the driver has a reputation to uphold. This is reinforced by research highlighting that there is a tendency for drivers to take responsibility for the safety and comfort of their passengers (Fleiter et al., 2010).

The present study tested the following hypothesis: the context associated with an organized carpooling results in safer driving behavior. Thus, this article aims to verify the hypothesis that drivers in an organized carpooling situation show safer driving behavior in terms of mobile phone use and speeding. The verification of the hypothesis is based on the comparison of road safety performance indicators related to the use of the mobile phone as a secondary task to driving and the practice of speeding in carpooling (CP) and non-carpooling (NCP) situations.

The methodology was based on collection of naturalistic driving data. NDS was considered a suitable methodology since it enabled the observation of real organized carpooling in which the relationship between driver and passenger involves a service supply with expected safety and comfort standards. This context would be difficult to reproduce in a simulated experiment and, therefore, capturing the influence of organized carpooling on driver's willingness to engage in risky behaviors, such as using the mobile phone or speeding, would also be a hard task using any methodology other than NDS. The possibility to observe environment-related variables, e.g. weather condition, presence of speed cameras and percentage of daylight driving time, also justified the choice for the NDS design.

In addition, the core of the discussion on the disadvantages of NDS in comparison with simulation experiments refers to NDS application for assessing the impact of potential distraction-causing tasks (e.g. mobile phone use) on driver's performance or in safety critical events studies using a number of safety performance indicators collected through on-board sensors (Simmons et al., 2016; Caird et al., 2018; Wijayaratna et al., 2019). That is not the case in the present research, which focuses on measuring the incidence and characterization of speeding and mobile phone use behaviors; thereby confirming NDS as a convenient methodology.

2. Material and methods

2.1. The Brazilian Naturalistic Driving Study (NDS-BR)

This research was conducted as part of the first Brazilian Naturalistic Driving Studay (NDS-BR). This naturalistic driving study was designed using the principle of "minimum value prototype", involving the non-intrusive instrumentation of vehicles to monitoring real driving. Each vehicle was equipped with three cameras, a laptop, a voltage inverter and a GPS (Global Positioning System) device. Two cameras faced the outside of the vehicle (front right and front left) and one camera (internal) faced the driver (Fig. 1). The laptop, positioned in front of the passenger seat, was programmed to activate the cameras and the GPS as soon as it was turned on after the vehicle started. The collection of video and geographic coordinates was synchronized and recorded each second.

Two risky behaviors were investigated: mobile phone use (MPU) while driving and speeding. MPU while driving was studied using behavioral coding on the videos. Driving speed was measured using information from the GPS device. This allowed capture of instantaneous speed whilst using the mobile phone as well as identifying speeding episodes and environment-related variables. In order to maintain the privacy of drivers and not to discourage mobile phone conversations, for example, there was no audio recording.

Drivers were recruited using on-line advertising. Drivers who completed an expression of interest were invited to participate in a focus group session on traffic behavior. The focus group session aimed to survey the participants' behavioral characteristics and filter out those who exhibited very extreme travel patterns or behaviors and, therefore, were not suitable participants. This process resulted in the selection of 4 drivers who occasionally practice organized carpooling through a mobile application.

Each driver used his/her private vehicle over a period of 2 weeks to maintain an approximation of their usual driving behavior. The collection began in August and ended in November, 2019. Drivers' ages varied between 19 and 38 years, there were 3 men and 1 woman, with the time that a driver license had been held varying between less than 1 year and up to 10 years. The year of manufacture of the vehicles varied from 2002 to 2012, all with manual transmission and with power ranging from 97 to 116 HP. The vehicle models were as follows: Chevrolet / Prisma, GM / Zafira, Renault / Scenic, and VW / Fox. None of the vehicles had a speakerphone system for making phone calls. The study was conducted in the city of Curitiba and its MetropolitanRegion, which is located in the south of Brazil and is predominantly urban.

The complete data collection for the 4 drivers who practice carpooling resulted in 108 trips, corresponding to 40.45 h and a distance of 895.87 km traveled, 98.96 % in urban areas. From that total amount, some portions of the trips had to be excluded. We ruled out each driver's first trip due to the driver's familiarization process with the equipment and classified the rest of the travel times as valid or not valid, excluding the sections considered as not valid from the analysis. We considered as not valid entire trips or trip sections without the video or GPS record file. Other time sections considered not valid, for example, were (i) the period between when the driver started the car and the monitoring system at the beginning of the trip and when they began driving; (ii) occasions when the driver parked but did not turn off the monitoring

Fig. 1. Images collected by cameras ([a] front left, [b] front right and [c] internal).

system and (iii) at the end of the trip, when the car is parked but the monitoring system is not yet turned off (Fig. 2).

2.2. *Detection of carpooling situations*

Carpooling situations were identified by consulting the smart phone application used by the drivers, who passed on their carpooling trip register information. The ride registration in the application contains information on the place and time agreed for the meeting between the driver and the passenger. We analyzed the in-vehicle recordings to identify the beginning and end times of the carpooling situations. The beginning of the carpooling situation was identified by observing the driver stopping and exchanging a few words with the passenger (by mouth movements). Likewise, to identify the end of the carpooling situation exactly, we searched for scenes when the driver stopped the vehicle and said some farewell words to the passenger. Another important indication of the beginning and end of the carpooling situation was the vibration of the camera image, caused by the passenger boarding/disembarking.

It is important to note that drivers were not subjected to any type of incentive to practice carpooling, and situations were identified along of each driver's travel routine. After completing the data collection, drivers responded to a questionnaire in order to identify the level of the relationship between the driver and the carpooling passengers. There were 17 passengers in all, with only 3 of them being related to one of the drivers. It was decided not to exclude passengers related to drivers, since it was considered that the use of a carpooling operator (smart phone application) presupposes a more impersonal relationship of service provision, even if there is some degree of kinship with the passenger. Additionally, the elimination of these trips would have an impact on the sample size of carpooling situations, which is already low.

2.3. *Monitoring of speeding*

The methodological steps for monitoring of speeding are shown in Fig. 3. The first part consisted of a data treatment procedure using the software QGIS® (Steps 1–3) and the OpenStreetMap® georeferenced database, considering only the valid trip time records. In Step 1, since the OpenStreetMap® database does not contain the speed limit data for all roads in Curitiba and the Metropolitan Region, we imputed the speed limit (SPL) according to the road hierarchy defined in local urban planning legislation. The removal of remaining road segments without SPL information resulted in a reduction of 89.95 km in the length of roads that comprised the sample.

In Step 2, we disregarded the geographical coordinate points recorded at a distance of more than 10 m away from the road. Such cases occurred due to occasional inaccuracy of GPS during the NDS-BR, which resulted in geographical coordinates being recorded for places not on the road; consequently, generating an unreliable speed calculation. The removal of inaccurate points resulted in a reduction of 34.40 km in the road length considered. Thus, the total covered distance available for analysis was 771.52 km, that is, a 13.88 % reduction in relation to the total 895.87 km traveled.

In Step 3 we compared the instantaneous speed with the speed limit for each road, only considering trip segments along road sections with a known speed limit. The computation of the share of traveled distance, or vehicle-kilometers traveled (VKT), undertaken while speeding depends on the definition of a reference distance (denominator) – Steps 3.1–3.2 (Fig. 3). In Steps 3.1a and 3.1b, we considered all VKT as the denominator in computation of the indicators "percentage of vehicle-kilometers traveled over the speed limit (SP)", at any speed, and "percentage of vehicle-kilometers traveled at a speed greater than 10 % below the speed limit (SP>10 %)". These two levels of speeding helped us to differentiate between an attention-related error and intentional speeding. For SP and SP>10 % we excluded very short trips (length less than or equal to 786 m) in both hypothesis testing procedures. Thus, we computed SP and SP>10 % for 17 CP trips and 99 NCP trips.

In Step 3.2, we considered only the VKT at a speed higher than the speed limit minus 10 km/h (SP - 10 km/h) as a free-flow episode, for example, if the SPL was 60 km/h, the reference value was the VKT at a minimum speed of 50 km/h. The choice for this speed range intended to consider situations which driver had the opportunity to speed, since there was no evident constraint by any other operational aspect in the driving environment, based on previous literature that adopted a threshold of 8.04 km/h (5 mph) below the posted speed limit (NHTSA, 2012; Richard et al., 2013). The rationale is that these situations are more likely to be those in which drivers could choose to speed, whereas total VKT includes numerous situations where driver speed is

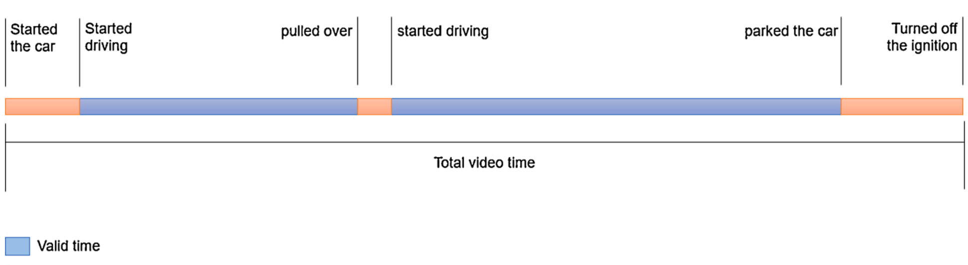


Fig. 2. Valid and not valid time situations.

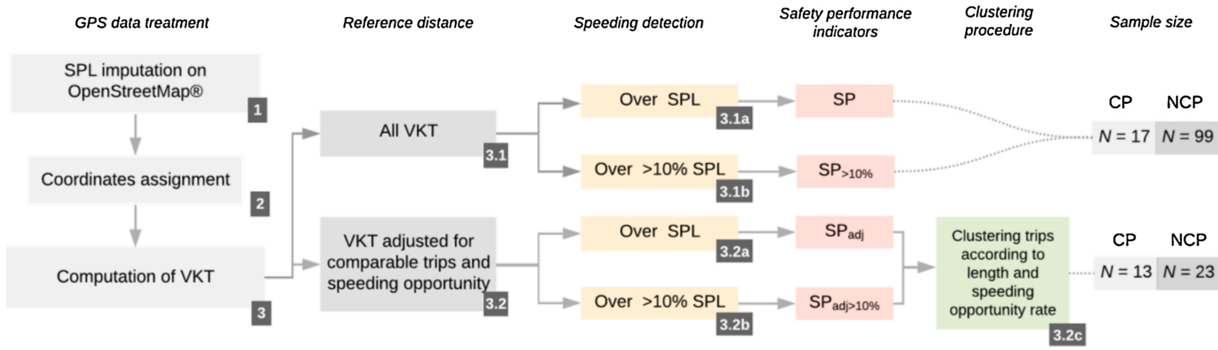


Fig. 3. Methodological steps for speeding monitoring.

constrained by traffic. Even though we explore the differences between CP and NCP trips in sections 3.1 and 3.2 of the results, there are some methodological considerations regarding trip length and the speeding opportunity. Organized CP trips tend to be attractive for longer journeys, this is, for greater trip lengths (Teal, 1987; Ferguson, 1997; Chung et al., 2011). In addition, having in mind the speeding opportunity concept addressed earlier (speed higher than the speed limit minus 10 km/h), it is important to consider that the typical use of CP for commuting during the morning (during the more concentrated travel demand peak) influences the speeding opportunity rate. In other words, since CP trips tend to occur during periods of the day with more congestion, the speeding opportunities tend to be scarce. This might affect drivers' decisions to speed when there is a speeding opportunity, manifesting a sort of compensatory behavior: when the speeding opportunity arises, driver willingness to speed might be higher, and the driver might also exceed the speed limit at a higher level.

For this reason, in Step 3.2c, in addition to the speeding opportunity, we considered comparable characteristics of CP and NCP trips. We analyzed the trips' similarity level through a hierarchical clustering procedure using median linkage and Squared Pearson Distance to group CP and NCP trips (observations) in terms of their length (in kilometers) and speeding opportunity rate (in percentage of the total trip length). The dendrogram of Fig. 4 shows a good similarity level (higher than 80 %) for the 4 established groups, in which the dashed green square contains 13 of 17 CP trips (76.47 %) and 16 of 99 NCP trips (16.16 %). Moreover, we excluded an NCP trip that occurred on a Saturday, since all CP trips occurred during weekdays, so the sample size of NCP trips reduced to 15 (15.15 %). These methodological decisions were taken in an attempt to reduce the impact of confounding factors on the relationship between CP and speeding behavior.

The remaining $N = 28$ sample encompasses the comparable CP and NCP trips – with an average length of 12.46 km (SD =3.27 km) and a speeding opportunity rate of 53.41 % (SD = 14.92 %). Hence, in steps 3.2a and 3.2b, we considered the VKT adjusted for speeding opportunity as the denominator in computation of the indicators "percentage of vehicle-kilometers traveled over the speed limit adjusted for speeding opportunity and comparable trips (SP_{adj})" and "percentage of vehicle-kilometers traveled at a speed greater than 10 % below the speed limit adjusted to speeding opportunity and comparable trips ($SP_{adj>}10$ %)". We computed SP_{adj} and $SP_{adj}>10$ % for 13 CP trips and 15 NCP trips.

Therefore, it is expected that trips with comparable speeding opportunity rate also indirectly present: (i) comparable traffic density (vehicles / km), since traffic congestion speed tends to be lower than the minimum free-flow speed (speed limit minus 10 km/h); (ii) comparable density of traffic lights (traffic lights / km), because speed during the process of stopping on red light tends to be lower than the minimum free-flow speed; and (iii) comparable density of horizontal curves (turning maneuver / km), since speed along turning maneuvers tends to be lower than the minimum free-flow speed. Such combined variables, commonly found in urban environment, are essential for determining trip speeding opportunity rate. The higher the mentioned densities are, the lower is the speeding opportunity rate.

In order to evaluate potential effect of additional heterogeneity sources on the considered set of 28 trips, it was also possible to observe information on weather condition ("raining" and "not raining") and on the density of fixed speed cameras along every trip (in speed cameras /

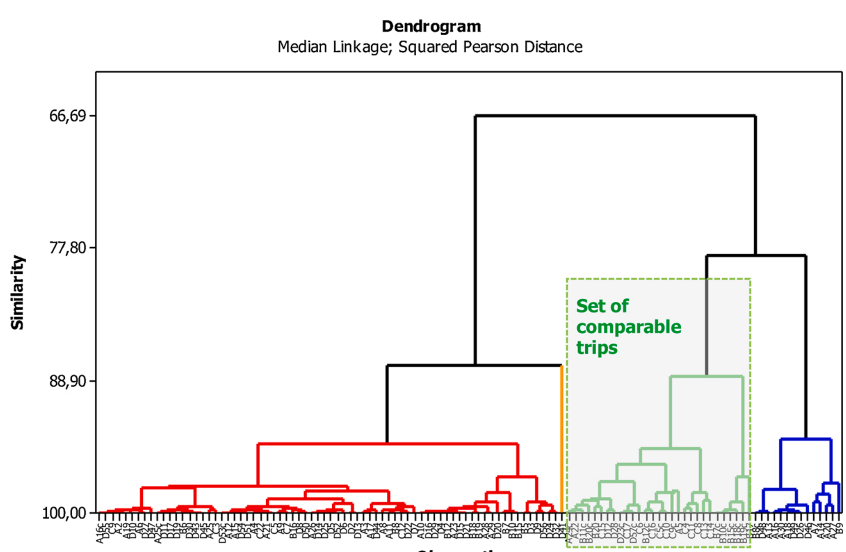


Fig. 4. Comparable CP and NCP trips in terms of trip length and speeding opportunity rate.

km). These factors might have a great impact on the speeding behavior, since rainy weather (Dinh and Kubota, 2013; Jägerbrand and Sjöbergh, 2016) and presence of automated speed enforcement (Srinivas et al., 2018; Pantangi et al., 2020; Singh and Kathuria, 2021) tend to favor lower speeds. Rainy weather was observed in 1.65 % of the travel time in CP situation, whereas no raining episode occurred in NCP situation. The density of speed cameras was 0.44 speed cameras / km ($SD = 0.18$) in CP situations and 0.50 speed cameras / km ($SD = 0.28$). Even though the density of speed cameras in CP is lower than in NCP situations, the difference was not statistically significant according to nonparametric Wilcoxon signed rank test ($W = 174.0$, $p = 0.519$). Moreover, the percentage of daylight driving time based on the time of sunrise and time of sunset was collected, accordingly: 91,27 % of driving time was under daylight condition in CP trips, while in NCP trips it was 78,38 %.

The statistical analysis of speeding behavior consisted of two procedures, being first the application of hypothesis tests in order to verify if there are statistically significant differences at the 95 % confidence level (95 % CI) on the 4 mentioned speeding indicators for the CP and NCP situations, i.e., whether CP situations tend to present lower values for SP, $SP_{>}10$ %, SP_{adj} and $SP_{adj>}10$ %. Due to the small sample size, we applied the nonparametric Wilcoxon signed rank test. The resulting sample size composed by a set of comparable trips was N = 28 ($N = 13$ for CP situations and $N = 15$ for NCP situations).

In order to double-check the results, we employed the Pearson Chi-Square test to check the association between CP vs NCP and the corresponding speeding indicator (SP, $SP_{adj>}10$ %, SP_{adj} and $SP_{adj>}10$ %). The limited sample size justifies the translation of each safety performance indicator value into a binary response using the opposing categories “low” and “high”, “low” being for speeding indicator values lower than or equal to the median of the entire sample, including CP and NCP situations. The choice of the median was intended to split the sample into two similar parts of low and high values.

2.4. MPU monitoring

The internal camera enabled the identification of the behaviors that triggered the MPU criteria. Table 1 shows the MPU types we identified in this paper, their description, as well as the criteria for beginning and end of the MPU. Additional details on this method are provided elsewhere (Bastos et al., 2020).

A trained team of researchers performed video analysis of the internal camera, and identified a total of 627 MPU. It was possible to produce 4 road safety performance indicators: MPU_T – Average MPU time (s); MPU $_{PT}$ – Proportion of driving time with MPU (%); MPU_F – MPU frequency (uses/hour); MPU_S – Average instantaneous speed during MPU (km/h). Only MPU during a valid driving time (see Fig. 2) was considered valid for the purpose of measuring MPU time. Whenever the driver lost visual and manual contact with the device, it was considered that a distinct MPU event had been terminated.

The statistical analysis consisted of two procedures, being first the application of hypothesis tests in order to verify if there are statistically significant differences at the 95 % confidence level (95 % CI) on the 4 mentioned indicators for the CP and NCP situations, i.e., if CP situations tend to present lower values for MPU_T, MPU_{PT}, MPU_F and MPU_S. Depending on the normality of the data distribution, which we checked using the Anderson-Darling test, we applied either the parametric one-way ANOVA test or the nonparametric Wilcoxon signed rank test. For 3 of the 4 indicators, even the limited sample of CP cases or the data distribution did not allow use of parametric methods. In addition, we used the Pearson Chi-Square test to check the association between CP vs NCP and the type of MPU.

Again we applied the Pearson Chi-Square test to verify the association between CP vs NCP and the MPU indicator value. The comparison between two situations (CP and NCP) and the limited sample size justify the translation of each safety performance indicator value into a binary response using the opposing categories “low” and “high”, with “low”

Table 1
MPU situations and criteria for its beginning and end.

Type of use	Description	Criteria	
		Beginning	End
Texting	Touches on the screen with one or both hands several times in a row	When the driver moves his / her hand towards the device	When the driver drops the device and resumes eye contact with the route, or engages in another secondary task
Calling/ voice message	Use the hand for calls or to send / listen to audio in apps	When the driver moves his / her hand towards the device	When the driver drops the device and resumes eye contact with the route, or engages in another secondary task
Holding	Hold the mobile phone, while looking in a direction other than where the device is	When the driver moves his / her hand towards the device	When the driver drops the device and resumes eye contact with the route, or engages in another secondary task
Use on-holder	Use the mobile phone while it is on a holder fixed to the vehicle's panel / internal windscreen	When the driver moves his / her hand towards the device	When the driver loses manual contact with the device and resumes eye contact with the route, or engages in another secondary task
Checking/ browsing	Touches the screen, maintaining visual and / or manual contact with the mobile phone, in order to view information	When the driver moves his / her hand towards the device	When the driver drops the device and resumes eye contact with the route, or engages in another secondary task
Other	Use mobile phone for various purposes, such as taking photos or using the flashlight	When the driver moves his / her hand towards the device	When the driver drops the device and resumes eye contact with the route, or engages in another secondary task

being for MPU indicator values lower than or equal to the median of the entire sample, including CP and NCP situations.

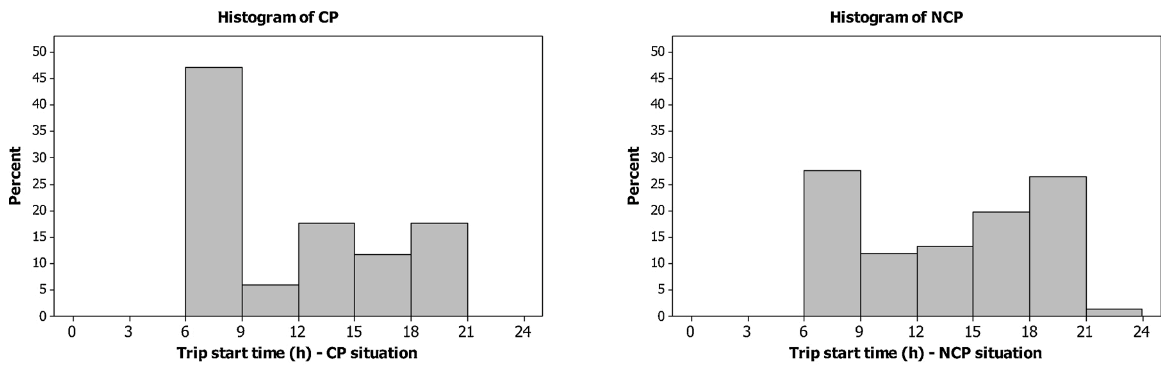
For MPU_{PT} and MPU_F, we excluded trips where these values were zero in both hypothesis testing exercises, because they might represent a situation without any opportunity to use a mobile phone, therefore, drivers were not exposed to this sort of distraction. Moreover, since each MPU_{PT} and MPU_F value corresponded to a single trip, there was a small resulting sample size of CP trips ($N = 16$).

3. Results and discussion

3.1. Characteristics of the trips recorded in the NDS-BR

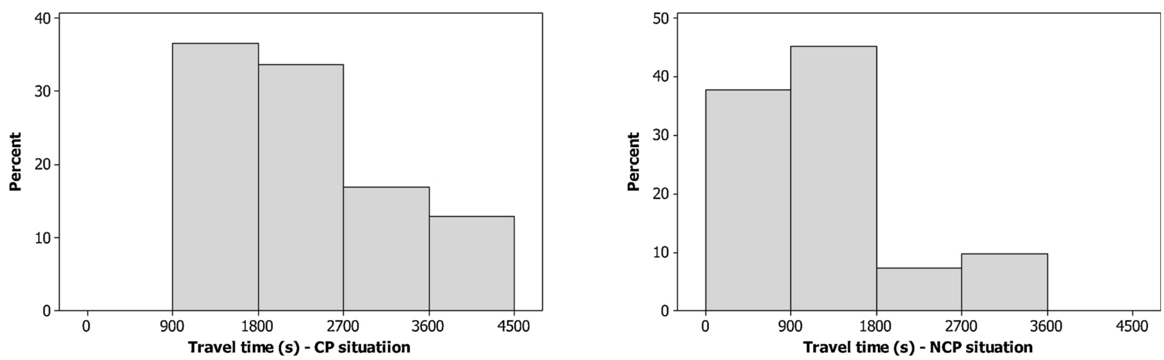
Of the total monitored trips ($N = 116$), 87.62 % occurred on weekdays, 9.52 % on Saturdays and 0.95 % on Sundays. From Monday to Friday, there was an average of 2.30 trips per day ($SD = 0.33$), while on weekends this figure was 0.81 ($SD = 0.97$). Regarding CP trips, none occurred on the weekends, being 17.65 % on Mondays, 29.41 % on Tuesdays, 29.41 % on Wednesdays, 17.65 % on Thursdays, and 5.88 % on Fridays, presumably for work and study purposes. The temporal distribution of CP trips is more concentrated in the morning peak, with 47.06 % of CP trips starting between 7 and 9 a.m., compared with only 27.63 % of NCP trips (see Fig. 5). The reason for the higher concentration of CP trips in the morning peak is probably associated with easier planning possibilities at the beginning of the work/study day compared to the end of the day.

CP trips were of longer duration ($W = 1203.0$, $p < 0.001$), with no trips lasting less than 15 min, and all completed within 1 h and 15 min (Fig. 6). In contrast, the NCP situation corresponded to shorter trips,



[a] [b]

Fig. 5. Histogram of trip start times in CP [a] and NCP [b] situations.



a] [b]

Fig. 6. Cumulative histogram of travel times in CP [a] and NCP [b] situations.

since 38.16 % of the trips lasted up to 15 min, that is, 61.84 % of the trips lasted between 15 min and 1 h. Similarly, NCP trips were shorter (W = 1474.0, $p < 0.001$); the average traveled distance in CP trips was 10.86 km (95 % CI [8.28; 13.43]), while in NCP the average trip length was 5.86 km (95 % CI [5.16; 6.56]). These findings are consistent with the expectation that CP journeys might be longer due to the need for route deviations to pick up the passenger(s), so that the trip has to be long enough to compensate this extra time spent.

As a consequence of the distribution of CP trips over weekdays and Fig. 5 related findings (CP concentration in peak hours), CP trips had lower speeding opportunity rate (W = 589.0, $p < 0.001$). The mean speeding opportunity rate in CP trips was 46.48 % (95 % CI [38.84; 54.11]), while the mean speeding opportunity rate in NCP trips was 60.12 % km (95 % CI [56.54; 63.71]).

3.2. Speeding behavior analysis

Speeding behavior values of SP, $SP_{>}10$ %, SP_{adj} and $SP_{adj>}10$ % across both situations (CP and NCP) were 27.54 % (SD = 13.38 %), 20.79 % (SD = 12.41 %), 53.46 % (SD = 12.13 %), and 42.32 % (SD = 12.84 %), respectively. The values were lower when no adjustment on the reference distance is considered (SP and $SP_{>}10$ %). It increases to 53.46 % when we took into account the comparable trips adjustments (SP_{adj}), which means that if drivers have the opportunity to speeding in 100 km, they will do it along 53.46 km. If we consider as speeding above a 10 % of the speed limit, this value decreases 20.83 % ($SP_{adj>}10$ % = 42.32 %). Table 2 presents the comparison of the safety performance indicator related to speeding in CP and NCP situations.

Since we defined all indicators as having effects in the same direction, the higher the indicator value is, the worse is the road safety performance. We found statistically significant differences at the 95 % confidence level for the SP indicator (W = 750.0, p = 0.028). No statistically significant differences at the 95 % confidence level were found for $SP_{>}10$ %, SP_{adj} and the $SP_{adj>}10$ %.

Table 3 contains the results of the Pearson Chi-Square tests applied to check the association between CP vs NCP and the speeding indicators (SP, $SP_{>}10$ %, SP_{adj} and $SP_{adj>}10$ %). The recoding of the speeding indicators values into a binary variable (low or high percentage of traveled distance under speeding condition) indicated that CP situations exhibited mostly low percentages of speeding behavior. However, Pearson Chi-Square tests indicated that this assumption is not statistically significant at the 95 % confidence level (95 % CI) for any speeding indicator: SP – χ^2 (1, N = 116) = 3.377, p = 0.066; $SP_{>}10$ % – χ^2 (1, N = 116) = 1.723, p = 0.189; SP_{adj} – χ^2 (1, N = 28) = 3.590, p = 0.058; and $SP_{adj>}10$ % – χ^2 (1, N = 28) = 1.292, p = 0.256.

3.3. MPU while driving analysis

The MPU as a secondary task to driving occurred in 76.03 % of trips in any situation (CP or NCP), with an average duration of 28.51 s (95 % CI [24.77; 32.26]), a percentage of the travel time with MPU of 9.82 % (95 % CI [7.53; 12.12]), a frequency of 15.68 MPU/hr (95 % CI [13.60; 17.77]) and an average instantaneous speed during the MPU of 7.94 km/h (95 % CI [6.66; 9.22]).

Table 4 contains the comparisons of the CP and NCP situations in terms of the four road safety performance indicators related to the surveyed MPU_T, MPU_{PT}, MPU_F and MPU_S, as well as the values of the hypothesis tests performed to assess the statistical significance of the comparisons. For three of the indicators associated with the MPU (MPU_T, MPU_{PT} and MPU_S), we found a statistically significant difference

Table 2
Speeding road safety performance indicators – Hypothesis tests (Wilcoxon rank-sum).

Speeding indicator	Statistical parameter	CP	NCP
SP	N	17	99
% of total VKT over SPL	Mean (%)	22.10	28.47
	Confidence interval (95 %)	(17.67; 26.52)	(25.71; 31.23)
N = 116	Median (%)	22.55	28.20
Wilcoxon rank-sum		*W = 750.0, p = 0.028*	
$SP_{>10\%}$	N	17	99
% of total VKT more than 10 % over SPL	Mean (%)	17.71	21.31
$N = 116$	Confidence interval (95 %)	(14.33; 21.10)	(18.70; 23.72)
	Median (%)	18.26	20.04
	Wilcoxon rank-sum	*W = 888.0, p = 0.204*	
SP_{adj}	N	13	15
% of total VKT over SPL adjusted by speeding opportunity and comparable trips	Mean (%)	49.63	56.78
$N = 28$	Confidence interval (95 %)	(44.69; 54.56)	(48.93; 64.63)
	Median (%)	48.03	56.26
	Wilcoxon rank-sum	*W = 158.0, p = 0.084*	
$SP_{adj>10\%}$	N	13	15
% of total VKT more than 10 % over SPL adjusted by speeding opportunity and comparable trips	Mean (%)	39.77	44.53
$N = 28$	Confidence interval (95 %)	(35.26; 44.27)	(35.62; 53.44)
	Median (%)	37.36	45.57
	Wilcoxon rank-sum	*W = 170.0, p = 0.2035*	

CP – Carpooling.
NCP – Not carpooling.

Table 3
Speeding road safety performance indicators – Hypothesis tests (Pearson Chi-Square).

Speeding indicator	Statistical parameter	CP	NCP
SP % of total VKT over SPL	$SP \le$ Median (low)	70.59 %	46.46 %
$N = 116$	$SP >$ Median (high)	29.41 %	53.54 %
Median = 27.09 %	Pearson Chi-Square	$\chi^2 = 3.377$, p = 0.066	
$SP_{>10\%}$ % of total VKT more than 10 % over SPL	$SP_{>10\%} \le$ Median (low)	64.71 %	47.47 %
$N = 116$	$SP_{>10\%} >$ Median (high)	35.29 %	52.53 %
Median = 19.00 %	Pearson Chi-Square	$\chi^2 = 1.723$, p = 0.189	
SP_{adj} % of total VKT over SPL adjusted by speeding opportunity and comparable trips	$SP_{adj} \le$ Median (low)	69.23 %	33.33 %
$N = 28$	$SP_{adj} >$ Median (high)	30.77 %	66.67 %
Median = 51.68 %	Pearson Chi-Square	$\chi^2 = 3.590$, p = 0.058	
$SP_{adj>10\%}$	$SP_{adj>10\%} \le$ Median (low)	61.54 %	40.00 %
% of total VKT more than 10 % over SPL adjusted by speeding opportunity and comparable trips $N = 28$	$SP_{adj>10\%} >$ Median (high)	38.46 %	60.00 %
Median = 43.38 %	Pearson Chi-Square	$\chi^2 = 1.292$, p = 0.256	

CP – Carpooling.
NCP – Not carpooling.

between the CP and NCP situations (Table 4), with the first situation presenting lower indicators and, therefore, a safer behavior.

The average duration of MPU (MPU_T) for those drivers in CP situation was 14.52 s (95 % CI [10.56; 18.48]), that is, 53.18 % less than the average duration of MPU for those drivers in NCP situation. The percentage of travel time using the mobile phone (MPU_{PT}) for drivers in CP situation was 5.31 % (95 % CI [2.66; 7.96]), in other words, 63.43 % less than the same indicator for drivers in NCP situation. The frequency of MPU (MPU_F) for drivers in CP situation was 11.60 MPU/hr (95 % CI [8.18; 15.03]), that is, 29.87 % fewer than the frequency for drivers in NCP situation, although this result was not statistically significant. Finally, the average instantaneous speed during MPU (MPU_S) for drivers in CP situation was 6.18 km/h (95 % CI [4.70; 7.66]), that is, 25.63 % lower than the average speed in NCP situations.

The translation of the MPU indicators' values into a binary variable showed that CP situations exhibited mostly low values, which indicates safer behaviors (Table 5). According to Pearson Chi-Square test, this assumption is statistically significant at the 95 % confidence level (95 % CI) for MPU_T, MPU_{PT} and MPU_S – χ^2 (1, N = 541) = 27.199, p < 0.001; χ^2 (1, N = 92) = 4.842, p = 0.025; and χ^2 (1, N = 541) = 5.208, p = 0.022, respectively. Regarding MPU_F, even though low values are predominant in the CP situation, the assumption is not statistically supported – χ^2 (1, N = 92) = 2.724, p = 0.099.

Driver behavior in CP and NCP situations also differed in terms of the type of MPU. The proportion of types of use that demand a higher level of visual and manual distraction was higher among NCP drivers, since the percentage of MPU for "texting" was 7.48 %, while among CP drivers the proportion was 4.58 % – 38.77 % lower – and the percentage of MPU for "calling / send voice message" was 6.20 %, while among CP drivers the proportion was 3.82 % – 38.39 % lower (Fig. 7). Other types of use, as described in Table 1, are not included in this analysis. Pearson Chi-

Table 4
MPU road safety performance indicators – Hypothesis tests (One-way ANOVA/ Wilcoxon rank-sum).

MPU indicator	Statistical parameter	CP	NCP
MPU_T	N	116	425
Time of MPU	Mean (s)	14.52	31.01
$N = 541$	Confidence interval (95 %)	(10.56; 18.48)	(26.59; 35.43)
	Anderson-Darling	*p < 0.005*	*p < 0.005*
	One-way ANOVA	*F = 13.86, p < 0.001*	
MPU_{PT}	N	16	76
	Mean (%)	5.31	14.52
% of trip time with MPU	Confidence interval (95 %)	(2.66; 7.96)	(11.37; 17.67)
$N = 92$*	Anderson-Darling	$p = 0.073$	$p < 0.005$
	Median (%)	4.51	10.04
	Wilcoxon rank-sum	*W = 465.0, p = 0.002*	
MPU_F	N	16	76
	Mean (MPU/hr)	11.60	16.54
Frequency of MPU	Confidence interval (95 %)	(8.18; 15.03)	(14.14; 18.94)
$N = 92$*	Anderson-Darling	$p = 0.786$	$p < 0.005$
	Median (MPU/hr)	*11.60*	*16.54*
	Wilcoxon rank-sum	*W = 585.0, p = 0.051*	
MPU_S	N	116	425
	Mean (km/h)	6.18	8.31
Speed with MPU	Confidence interval (95 %)	(4.70; 7.66)	(7.45; 9.18)
$N = 541$	Anderson-Darling	*p <0.005*	*p <0.005*
	Median (km/h)	*1.76*	*4.96*
	One-way ANOVA	*F = 5.31, p = 0.022*	

MPU – Mobile phone use.
CP – Carpooling.
NCP – Not carpooling.
* Values equal to zero were excluded.

Table 5
MPU road safety performance indicators – Hypothesis tests (Pearson Chi-Square).

MPU indicator	Statistical parameter	CP	NCP
MPU_T	$MPU_T \leq$ Median (low)	71.55 %	44.24 %
Time of MPU $N = 541$	$MPU_T >$ Median (high)	28.45 %	55.76 %
Median = 12 s	Pearson Chi-Square	$\chi^2 = 27.199$, $p < 0.001$	
MPU_{PT}	$MPU_{PT} \leq$ Median (low)	75.00 %	44.74 %
% of trip time with MPU $N = 92$*	$MPU_{PT} >$ Median (high)	25.00 %	55.26 %
Median = 7.89 %	Pearson Chi-Square	$\chi^2 = 4.842$, $p = 0.025$	
MPU_F	$MPU_F \leq$ Median (low)	68.75 %	46.05 %
Frequency of MPU	$MPU_F >$ Median (high)	31.25 %	53.95 %
$N = 92$* Median = 13.63 MPU/hr	Pearson Chi-Square	$\chi^2 = 2.724$, $p = 0.099$	
MPU_S	$MPU_S \leq$ Median (low)	59.48 %	47.53 %
Speed with MPU $N = 541$	$MPU_S >$ Median (high)	40.52 %	52.47 %
Median =4.48 km/h	Pearson Chi-Square	$\chi^2 = 5.208$, $p = 0.022$	

MPU – Mobile phone use.
CP – Carpooling.
NCP – Not carpooling.
* Values equal to zero were excluded.

Square test results – χ^2 (4, $N = 679$) = 109.398, $p < 0.001$ – indicated a statistically significant association between carpooling or not and the type of MPU.

4. Discussion

The findings concerning the comparison of the characteristics of CP and NCP trips are consistent with previous research that indicates that (i) CP trips mostly occur on weekdays (Teal, 1987; Ferguson, 1997; Chung et al., 2011), (ii) CP usually occurs on the morning commute (Minett, 2012), and (iii) CP tends to occur for longer trips (Teal, 1987; Ferguson, 1997; Chung et al., 2011). This degree of consistency with previous literature highlights the validity of the findings reported in the present study. Thus, the similarities of the characteristics of CP trips we used with previous investigation sustain the idea that the current sample tends to be representative of typical CP situations. It is important to highlight that this is the first study on carpooling and driver behavior conducted in Brazil or South America, which makes these findings very significant for an understanding of the uptake of these new technologies in the region.

Regarding the speeding analysis, it is important to highlight the need to perform procedures in order to consider the speeding opportunity and comparable trips, since its implementation might strongly impact the results. The clustering procedure demonstrated to be fundamental for conducting a fair comparative analysis between CP and NCP trips, thus, reducing a likely confounder effect associated with the traveled distance and the speeding opportunity rate. The indicators regarding the percentage of the total VKT over SPL adjusted by speeding opportunity and comparable trips (SP_{adj}) and the percentage of total VKT more than 10 % over SPL adjusted by speeding opportunity and comparable trips ($SP_{adj>}$10 %) manifest more precise measures of speeding behavior. In the case of SP_{adj}, hypothesis test results point in the same direction and partially confirm the initial assumption that the CP situation induces safer behavior in terms of speeding. Although there is no specific research in the area of carpooling, this finding is consistent with previous research suggesting that passengers have a slowing influence on drivers (Fleiter et al., 2010).

Regarding MPU use while driving, the results confirmed that there were lower values of MPU_T, MPU_{PT} and MPU_S for the situation of CP compared to NCP. In particular, the differences in MPU_T and MPU_{PT} were more pronounced. These results suggest that drivers primarily reduce their engagement by shortening the duration of the MPU rather than the frequency of engagement, i.e. MPU_T and MPU_{PT} than MPU_F and MPU_S. A potential explanation for this is that drivers can more easily perceive that they are using the mobile phone for a long time (for more than 4–5 s, for example), than realize that his frequency of use is above 11.89 MPU/hr. This perception of a possible exaggeration in the use of mobile phone on the part of the driver can be a determining factor for the inhibition of this risk behavior when in the presence of a carpool passenger, which has been already suggested as a protective factor (Metz et al., 2014; Tivesten and Dozza, 2015; Rosenbloom and Perlman, 2016; Christoph et al., 2019).

These results could be seen as a risk-compensatory strategy of drivers to prevent excessive workload from the secondary task, since drivers actively seek to reduce or manage the additional workload produced by mobile phone interactions by selecting types of MPU that are shorter (Oviedo-Trespalacios, 2019). Overall, this is consistent with emerging research showing that drivers can modify the duration and frequency of MPU while driving as a strategy to increase safety (Oviedo-Trespalacios et al., 2018). In addition, organized carpooling might work as a protective factor due to social pressure or norms, since a carpool passenger might disapprove risky behaviors, as well as economic risk, since risky CP drivers might receive bad evaluations and find less passengers for splitting costs. Nonetheless, it is important to remember that mobile phone use while driving is an extremely risky behavior that must be prevented (Li et al., 2019; Oviedo-Trespalacios, 2016; Oviedo-Trespalacios et al., 2019), so it is very concerning to see such levels of engagement in both CP and NCP trips.

However, given the limitations of the study, it is important to perform more research and to expand the NDS-BR to increase our understanding of Brazilian driver behavior. A larger sample size and geographical coverage, involving more Brazilian cities, is necessary to evaluate other characteristics (e.g. driver age and type of vehicle). The data collection period was limited to two weeks with the idea of minimizing potential annoyance caused by the laptop position (in front of the

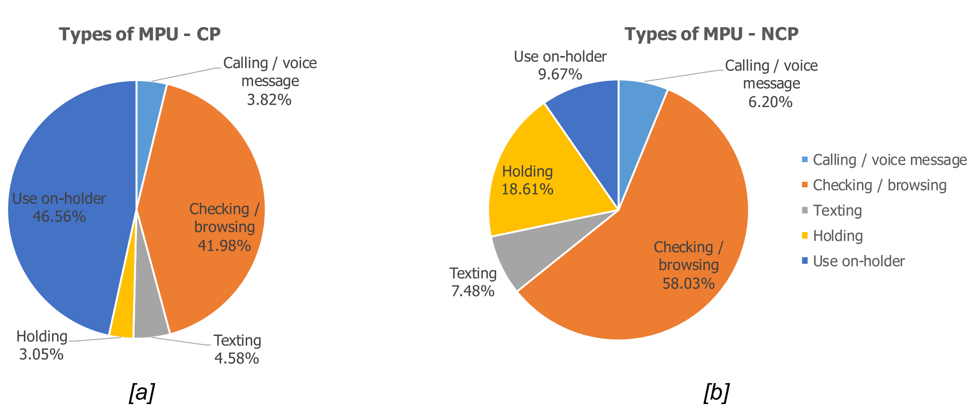


Fig. 7. Types of MPU in carpooling [a] and not carpooling [b] situations.

passenger front seat) for the organized carpooling passenger. In particular, regarding the speeding analysis, the attempt to conduct a fair comparison between CP and NCP trips and comparable trips by adjustments according to speeding opportunity (intended to control surrounding traffic influence, density of traffic lights and density of turning maneuvers) might not have been enough to control for, even though CP and NCP samples were quite similar regarding weather condition and density of fixed speed cameras. The limited sample size did not allow to take into account the differences regarding the percentage of daylight driving time. The lack of suitable controls is a problem acknowledged in previous research (Young, 2017; Wijayaratna et al., 2019).

Moreover, a more diverse group of participants would reduce driver heterogeneity and enable identification of human factors, types of bonds between driver and passenger, as well as age-specific determinants of driver behavior in organized carpooling. The focus group session performed to survey the participants' behavioral characteristics and filter out those who exhibited very extreme travel patterns or behaviors might have contributed to reduce driver heterogeneity. The consistency of the results with previous research also contribute for validation, as addressed earlier.

5. Conclusions

In summary, these results confirm the initial hypothesis of safer behavior during carpooling in terms of MPU while driving. With regards to speeding, most of the results were not statistically significant, except for the raw values of the percentage of the total vehicle-kilometers traveled over the speed limit. The investigation of two different kinds of risky behavior required the application of distinct methods in order to take into account possible confounding factors in the relationship between carpooling and the safety performance indicators. Speeding indicators seemed to be more susceptible to the influence of trip aspects such as trip length and traffic conditions, which in turn affect the speeding opportunity rate. Additionally, engagement in a mobile phone related task while driving might be triggered by an external stimulus, which we could not control in this research.

Even though comparing the results of this naturalistic study with simulator experiments would be interesting, to the best of our knowledge, it was not possible to find any study on organized carpooling using driving simulators. Additionally, the service and trust relationships between driver and passenger encompassed by an organized carpooling situation is hard to reproduce in a simulator experiment.

The NDS-BR presented itself as a valid and low-cost methodology that enabled the investigation of MPU and speeding, offering new insights on the average Brazilian driver behavior while driving. The present study results confirmed the hypothesis that the CP situation results in safer driver behavior. Although more research is necessary, we could suggest that carpooling can increase safety among motorists.

Declaration of Competing Interest

The authors report no declarations of interest.

CRediT authorship contribution statement

Jorge Tiago Bastos: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Pedro Augusto B. dos Santos:** Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Eduardo Cesar Amancio:** Investigation, Data curation, Writing - original draft, Visualization. **Tatiana Maria C. Gadda:** Resources, Writing - review & editing, Visualization. **José Aurélio Ramalho:** Conceptualization, Resources, Data curation, Funding acquisition. **Mark J. King:** Writing - review & editing, Supervision. **Oscar Oviedo-Trespalacios:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - review & editing.

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