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Investigating the factors behind cellphone-distracted crashes: Assessing injury severity among distracted drivers in states with and without cell phone bans

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ABSTRACT

Introduction: Distracted driving, particularly due to cellphone usage, poses a serious threat to road safety by diverting drivers' attention from the road to activities like calling, talking, and texting. This not only jeopardizes the safety of the drivers themselves but also puts other road users at risk. To address this issue, many states have enacted laws prohibiting cellphone use while driving. This study investigates the impact of such laws on the severity of driver injuries, focusing on a comparison between Connecticut and Florida. *Method:* The study examines four years of crash data, during which Connecticut banned handheld phone use while driving, while Florida allowed hands-free use and treated handheld phone use as a secondary offense. Using random parameter logit models with heterogeneity in means and variances, the analysis identified differences in risk factors contributing to driver injury severity in both states with and without a cellphone ban. *Results:* Despite variations in data collection methods and variables across states, the study aligns and compares commonly defined and measured variables from crash incidents. The analysis identified 26 statistically significant variables in both models, with only four variables consistently affecting all levels of driver injury severity. These common risk factors include the involvement of newer vehicles (less than five years old from the crash involvement), incidents involving shoulders, young drivers (under 30 years old), and seat belt usage. *Conclusions/Practical Applications:* The findings emphasize the importance of modern safety features in newer vehicles, improved roadside design, driver training, and law enforcement measures targeting younger drivers to promote seat belt usage and mitigate distracted driving risks.

1. Introduction

Driver distraction has emerged as a major global concern for road safety. Recent studies on vehicle crashes have highlighted that driver distraction has a more significant negative impact on driving safety than factors like alcohol intoxication and fatigue (Qin et al., 2019). The National Highway Transportation Safety Administration (NHTSA) defines distracted driving as any activity that diverts a driver's attention from safe driving (NHTSA, 2023). Notably, distracted driving contributed to 9% of total fatal crashes in the United States between 2012 and 2018, resulting in the deaths of nearly 23,000 individuals. In 2019 alone, there were 3,142 fatal crashes and 424,000 injuries reported by the NHTSA due to motor-vehicle accidents involving distracted drivers in the United States (NHTSA, 2023). The economic impact is also substantial, with distraction-related crashes estimated to have cost 39.7 billion U.S. dollars in 2010 (Blincoe et al., 2010) and at least 98.8 billion U.S. dollars in 2015 (NHTSA, 2019; NSC, 2017) in the United States alone. It is critical to understand the mechanisms behind distracted driving, particularly how cellphone-related distractions are intertwined with other types of distractions. When drivers use their cellphones, they not only divert their attention from the road but also experience cognitive, visual, and physical (or manual) distractions. These simultaneous distractions significantly impair driving performance, increasing the likelihood of crashes. In general, distractions can be categorized into four types, such as visual, auditory, cognitive, and physical (or manual), and these are elaborated on how they affect driving performance differently:

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Visual Distraction: Taking one's eyes off the road significantly impairs lane-keeping ability and increases the likelihood of missing critical information, such as traffic signals and road signs (Victor et al., 2005). For example, tasks like looking at a GPS or reading a message divert the driver's focus away from the driving environment, increasing the risk of collisions.

Auditory Distraction: Listening to something unrelated to driving, such as loud music or a phone conversation, can divert attention and impair the driver's ability to process auditory cues in the environment. This type of distraction may not require looking away from the road but can still significantly reduce situational awareness.

Cognitive Distraction: Mental tasks that take the driver's mind off driving, such as engaging in a phone conversation, can lead to inattention blindness. Drivers might look directly at objects but fail to "see" them or react to them appropriately because their cognitive resources are engaged elsewhere (Strayer & Drews, 2007). Cognitive distractions also result in fewer saccades, more time looking centrally, less time checking mirrors, and increased incidents of hard braking (Harbluk, Noy, & Eizenman, 2002).

Physical Distraction: Taking one's hands off the wheel to perform a manual task, such as adjusting the radio or eating, can impede vehicle control. Physical distractions hinder the driver's ability to respond quickly and appropriately to road conditions and emergencies (Stutts et al., 2001).

Mobile device engagement, encompassing texting and phone use, stands out as the most prevalent distraction faced by drivers, exerting a substantial impact on driving performance, which includes reaction time, speed maintenance, and decision-making. (Caird et al., 2008; Chaudhary et al., 2012; Fitch et al., 2013; Simmons et al., 2016). Texting while driving is particularly dangerous as it combines visual, cognitive, and physical distractions. Research indicates that texting can significantly impair driving performance, leading to increased reaction times, lane deviations, and the likelihood of collisions. On the other hand, whether handheld or hands-free, phone conversations primarily cause cognitive distraction, which can still be significantly detrimental to driving safety (NTSB, 2023). The prevalence of cellphones has skyrocketed, reaching 97 % ownership in the United States by 2021 (Wu et al., 2022). Despite the rise of hands-free technology, personal electronic devices like cellphones and tablets serve persistently as significant contributors to driver distraction, as the conversation itself can lead to cognitive distraction (NTSB, 2023). As such, the evolution of laws addressing cellphone-related distractions and their adoption by different states has varied over time. Each state has developed and implemented its regulations, reflecting unique legislative approaches and responses to the growing awareness of the dangers associated with distracted driving. Understanding these variations is crucial for evaluating the effectiveness of these laws and identifying best practices that can be adopted nationwide to improve road safety.

1.1. Development of mobile phone distraction laws

Recognizing the gravity of distracted driving, several states in the United States have enacted laws to address the issue, particularly focusing on cellphone use while driving. Recognizing the gravity of distracted driving, several states in the United States have enacted laws to address the issue, particularly focusing on cellphone use while driving. The development of mobile phone distraction laws in the United States has evolved significantly over the years. In 2001, New York became the first state to establish a ban on using hand-held phones while driving, setting a precedent for other states to follow (Horwitt, 2002). By the end of that year, 43 states, the District of Columbia, and Puerto Rico were considering legislation on cellphone use on the road (Horwitt, 2002). Initially, these efforts focused primarily on banning hand-held devices, which were easier to regulate and enforce than hands-free alternatives.

Over time, the scope of these laws expanded. By 2021, 27 states and various U.S. territories had implemented comprehensive bans on hand-held phone use for all drivers, with most states enacting laws against texting while driving (Shoots-Reinhard et al., 2023). Additionally, specific restrictions were placed on novice and school bus drivers, acknowledging their higher risk profiles. For example, as of October 2016, 14 states had enacted hand-held CPWD bans applicable to all drivers, 46 states had passed texting-while-driving bans for all drivers, and 37 states banned any cellphone use for young or inexperienced drivers (Horwitt, 2002; Shoots-Reinhard et al., 2023).

Internationally, many countries had already imposed strict bans on mobile phone use while driving, setting precedents that influenced U.S. policies. Several nations, including Israel, Japan, and Singapore, implemented comprehensive prohibitions on all mobile phone use by drivers. Other countries, such as Australia, Germany, and the United Kingdom, specifically banned the use of hand-held mobile phones while driving (Horwitt, 2002). These international regulations provided valuable frameworks and examples for U.S. legislators to develop and refine their own laws aimed at mitigating driver distraction and enhancing road safety.

Recent laws have continued to address the evolving landscape of mobile phone use. In 2019, Minnesota became the latest state to pass a hands-free law, requiring drivers to use hands-free devices if they need to use their phones while driving (Shoots-Reinhard et al., 2022). These progressive measures reflect the growing recognition of the dangers associated with mobile phone use while driving and the efforts to mitigate these risks through legislative action.

Connecticut and Florida are two states that have implemented legislation to combat this problem. According to the Governors Highway Safety Association (GHSA), as of November 2013, in 12 states including Connecticut, a ban on handheld cellphone use while driving was implemented, prohibiting drivers from using their phones for any reason, including texting or talking, unless utilizing a hands-free device. Violators can face fines ranging from $150 to $500 for the first to the third or subsequent violation. In Connecticut, a comprehensive ban on handheld cellphone use while driving was implemented, covering all drivers, and even novice drivers were prohibited from using any mobile electronic devices while driving, including hands-free devices (CT CDR, 2023). On the other hand, Florida initially treated texting while driving as a secondary offense but later upgraded it to a primary offense. In July 2019, the state of Florida passed a law and became the 45th state to make texting while driving a primary offense, allowing law enforcement officers to stop and ticket drivers solely for that offense (GHSA, 2019). While both states addressed the issue of cellphone use while driving, their approaches were different in terms of the scope of the bans and enforcement. These variations in legislation reflect the different priorities and strategies adopted by each state to tackle the issue of distracted driving.[1]

Given these differences in approach between Connecticut and Florida, this paper aims to provide a comprehensive analysis of the factors influencing crash injury severity related to cellphone (i.e., electronic device) use in both states. The effectiveness of the laws on crash injury severity triggered by distracted driving related to cellphone use has been investigated and compared using crash data from 2015 to 2018[2] (inclusive). By comparing the injury severity of crashes associated with cellphone and electronic device use in these states, we intend to gain a better understanding and insight into the effectiveness of different approaches to legislating and enforcing cellphone bans. The findings of this study are intended to contribute to informed decision-making and guide future efforts aimed at enhancing road safety nationwide.

[1] The number of crashes between 2015 and 2018 in Florida was much higher than that in Connecticut. See Data section for more details.

[2] Florida enacted cell phone related texting ban in 2019. As such, 2019 crash data was not considered in this study to keep consistent analysis and comparison between the states of Connecticut and Florida.

The paper is organized as follows: it begins with a literature review focusing on multiple research studies on cellphone usage and risk factors, followed by a description of the crash dataset in Connecticut and Florida, and an overview of the variables used in the analysis. The methodology, model estimations, results, and discussions follow, leading to a conclusion.

2. Literature review

2.1. Influences of mobile phone distraction laws on driving behavior

Cellphone usage, whether through handheld or hands-free forms, has been extensively studied for its association with driver distraction, encompassing manual, visual, and cognitive distractions. Numerous studies consistently demonstrate that using cellphones while driving significantly increases the risk of crashes (Guo et al., 2019; Caird et al., 2014; Olson et al., 2009; Victor et al., 2015; Asbridge et al., 2013). Additionally, self-reported studies have revealed that phone use among drivers is particularly prevalent among young drivers compared to older ones (AAA, 2008; Boyle & Lampkin, 2008). Due to the impact of cellphone usage on distracted driving, many states across the United States have introduced laws targeting cellphone use while driving. However, the effectiveness of these laws in curbing cellphone use and mitigating crash severity varies due to differences in their scope and enforcement.

Regarding driver behavior change, previous studies have produced mixed results. Foss et al. (2009) and Goodwin et al. (2012) found that cellphone use bans had no significant effect on reducing cellphone use among young drivers in North Carolina, a finding later confirmed by Bradish et al. (2019) in Georgia. In contrast, other studies showed that bans on handheld use while driving led to a reduction in this behavior (Carpenter & Nguyen, 2015; Ehsani et al., 2014). A study by Liu et al. (2019) using interrupted time series analysis found that California's handheld cellphone ban was effective in reducing crashes caused by cellphone usage in terms of both crash frequency and crash proportion. The study also confirmed that crashes caused by cellphone use produce more severe outcomes than other crashes. Furthermore, the study found that the ban motivated drivers to switch from handheld cellphones to hands-free cellphones, although in terms of crash severity, hands-free and handheld cellphone usage did not show significant differences. These findings support a complete ban on cellphone use while driving, not just a prohibition of handheld cellphone use (Liu et al., 2019).

McCartt et al. (2014) reviewed evidence from various studies and found that all-driver bans on handheld phone conversations have resulted in long-term reductions in handheld phone use, and drivers in ban states reported higher rates of hands-free phone use and lower overall phone use compared with drivers in non-ban states. However, the effects of texting bans on the rates of drivers' texting are still unclear (McCartt et al., 2014).

Benedetti et al. (2022) found that drivers in states with handheld bans were 13% less likely to self-report talking on any type of cellphone (handheld or hands-free) while driving. Drivers in states with handheld bans were 38% less likely to self-report talking on a handheld phone and 10% more likely to self-report talking on a hands-free phone while driving. This supports the substitution hypothesis, indicating that handheld phone bans lead to increased hands-free phone use and a net reduction in overall phone use while driving (Benedetti et al., 2022).

2.2. Influences of mobile phone distraction laws on crash and injury risk

As for the effect of cellphone use bans on crash injury severity, Ferdinand et al. (2014) revealed that primarily enforced texting bans were associated with a significant 3% reduction in traffic fatalities across all age groups, with the most significant impact observed among young drivers aged 15–21 years. However, secondarily enforced restrictions showed no significant association with traffic fatality reductions. Lim and Chi (2013b) found that handheld cellphone bans targeting all drivers reduced fatal crashes involving young drivers, and their subsequent study highlighted the most significant impact of cellphone bans among drivers between 18 and 34 years (Lim & Chi, 2013a). Zhu et al. (2021), analyzing six years of crash data from 2006 to 2010 for the United States, found that comprehensive handheld bans were associated with a 7% reduction in the driver fatality rate, while texting bans were not associated with driver fatality rates. Similarly, Rudisill et al. (2018) reported that prohibitions on handheld calling from 2000 to 2014 were associated with a 10% reduction in driver fatalities but bans on texting while driving had no effect among drivers of all ages. In contrast, Flaherty et al. (2020) reported that bans on driver texting that allowed primary enforcement were associated with a 29% reduction in driver fatalities for ages 16–19 years and a 12% reduction for ages 40–55 years. Flaherty et al. (2020) also found that prohibitions of handheld calling were associated with a 26% reduction in driver fatalities for ages 16–19 years and a 24% reduction for ages 40–55 years.

Overton et al. (2015) found that mobile phone distraction resulted in 18% of fatal crashes and 5% of injury crashes in the United States. The study highlighted that legislation limiting drivers' cellphone use has had little impact, possibly due to low regulation and enforcement. Mobile phone distraction significantly increases crash risk and this study underscored the need for effective legislative measures to curb mobile phone use while driving.

In addition to examining the impact of safety policies and cellphone use bans on crash injury severity, researchers have investigated the effect of cellphone use on crash rate and severity. Haque and Washington (2014) concluded that drivers using mobile phones, whether handheld or hands-free, exhibit slower reaction times and increase crash risk. Table 1 provides an overview of key findings from selected studies that have examined the association of different types of cellphone use on crash rate and severity across various states.

3. Data description

The crash data used for this study were collected from two sources: the Connecticut Crash Data Repository (CRASH) (CT CDR, 2023) and the Florida Crash Analysis Reporting (CAR) system (CAR, 2022). The data covered the period from January 1, 2015, to December 31, 2018. The repositories provided separate tabular files for crash, driver, and vehicle levels. For the analysis, the individual dataset files were combined into a single file using common fields such as "CrashId" and "VehicleId," with a focus on driver-level information and injury status represented by individual rows. The data from Florida were linked using a common identifier, the "Crash ID."

The main focus of this paper is to investigate the crash injury severity of distracted drivers related to cellphone and electronic device usage. During the period from January 2015 to June 2019, Connecticut prohibited drivers from using handheld phones for talking and texting, while Florida allowed hands-free usage and considered the use of handheld phones a secondary offense. Hence, for the Connecticut data, records about drivers distracted by "Manually Operating an Electronic Communication Device (texting, typing, dialing)," "Talking on a Hand-Held Electronic Device," and "Talking on a Hands-Free Electronic Device" were selected for analysis. Similarly, "electronic communication device use (cellphone)" and "texting" were filtered under "driver distracted by." Both single-vehicle and multi-vehicle crashes were included in the crash data. To focus on the specific issue of distracted driving, single-vehicle crashes involving only drivers were filtered out from the Connecticut and Florida crash databases. Such crashes typically involve a driver colliding with fixed or moving objects, such as trees, poles, debris, etc.

The injury severity of drivers in single-vehicle cell-phone distraction in Florida and Connecticut is considered with possible injury outcomes of no injury (Property-Damage-Only (PDO)), minor injury (possible injury (C) and non-incapacitating injury (B), and severe injury (incapacitating injury (A) and fatality (K)).

Table 1
Summary of Key Findings from Studies on Distracted Driving due to Cellphone.

Objective	Methodology	Data	Key findings	References
Examine the effects of cellphone use and driver gender on collision avoidance.	A driving simulator	Experiment data from 45 participants	Hands-free condition did not eliminate the safety problem associated with distracted driving. Females tended to keep larger safety margin with the leading vehicle than males.	Li et al (2016)
Examine the relationship between cellphone usage while driving and risk of a crash or near crash	In-vehicle video	Naturalistic driving data (data from 105 participants)	The risk of a near-crash/crash event was approximately 17 % higher when the driver was interacting with a cellphone	Farmer et al (2015)
Explore the effect of drivers' use of mobile (cell) phones on road safety.	A case-crossover study (using interviews)	56 drivers aged ≥17 years owned or used mobile phones and had been involved in road crashes necessitating hospital attendance. (April 2002- July 2004)	Driver's use of a mobile phone up to 10 min before a crash was associated with a fourfold increased likelihood of crashing	McEvoy et al (2005)
Investigate temporal stability of cellphone-involved crash injury severities.	Random parameters logit models with heterogeneity in means and variances.	Single-vehicle crash datasets of Pennsylvania from (2004–2019)	Driving without seatbelts and overturns are observed to produce relatively stable and positive influence on the increased injury severities of cellphone-involved crashes. A combination of cellphone usage with risky driving behaviors (aggressive driving, alcohol- or drug-related driving, speeding, or fatigue driving) significantly increases driver injury-severities.	Wu et al (2022)
Analyze the cellphone crashes of novice teenagers (aged 15–17 years) to discover the grouping of contributing factors by crash severity levels and cellphone usage types.	The association rule mining (ARM) method	Louisiana crash data (2015–2019)	Single-vehicle crashes are associated with cellphone manipulation while driving on weekends in cloudy weather.	Hossain et al (2022)
Explore the influential factors of roadway departure crashes on rural two-lane highways.	A logit model	Louisiana crash data (2005–2017)	Cellphone use while driving could be 1.527 times more likely to result in a roadway departure crash than a non-departure crash.	Rahman et al (2021)
Evaluate the influence of cellphone use distraction on single-vehicle run-off road crashes.	The association rule mining ARM) method	Louisiana crash data (2014–2018)	The SVROR crashes with cellphone use are highly associated with non-usage of safety restraints, weekends, both lighted and unlighted dark conditions, undivided two-lane highway roads, and roadway curves.	Rahman et al (2023)
Examine the correlation between individual crash risk and cellphone use.	Negative binomial regression models	NDS data from SHRP-2 (the second Strategic Highway Research Program)	Overall crash rate increases 0.41 % for every additional text per day and 6.46 % for every text per hour of driving. The texting rate for young drivers is substantially higher than for middle-aged and senior drivers.	Atwood et al (2018)
Explore the relationship between engagement in various modes of cellphone use and the risk. of being involved in a crash.	A case-crossover study design	NDS data from SHRP-2 (the second Strategic Highway Research Program)	Crash involvement due to cellphone use while driving has an odds ratio of 1.83 about driving without cellphone use.	Owens et al (2018)
Investigate the association between the crash injury severity and the existence and type of driver distraction as well as driver age.	An ordered logit model	Crash data from the U.S. NationalAutomotive Sampling System's General Estimates System (2003–2008)	For older drivers, the highest odds of severe injuries were observed with dialing or texting on a cellphone, followed by in-vehicle sources and talking on the cellphone. Talking on cellphones had a similar effect for younger drivers but was not significant for mid-age drivers.	Donmez and Liu (2015)
Investigate factors affecting single vehicle crashes in California.	A mixed logit model	California Crash Data (2003–2004)	The ban was found effective in reducing crash frequency and crash proportion. Also, the study confirmed that the crashes caused by cellphone use produce more severe outcomes than other crashes.	Kim et al (2013)
Explore the effectiveness of the cellphone usage ban on crash frequency and crash proportion in California.	Negative Binomial (NB) regression model	California crash data from 2002 to 2014 collected from Highway Safety Information System (HSIS)	Cellphone usage was somewhat related to injury severity in single-vehicle crashes.	
Investigate the effectiveness of the cellphone ban and texting ban on crashes.	Review 11 peer-reviewed papers	Papers and reports of all-driver hand-held phone bans and texting bans	The results varied widely. The lack of appropriate controls and other challenges in conducting strong evaluations limited the findings of some studies. Thus, it is unclear whether they are having the desired effects on safety.	McCartt et al. (2014)

After cleaning the data and removing records with missing information, the analysis was conducted on 984 observations in Connecticut and 3,733 observations in Florida for single-vehicle crashes from 2015 to 2018 (inclusive). The overall crash data were categorized based on several characteristics: spatial, temporal, environmental, traffic, vehicular, crash, roadway, and driver. The spatial characteristics include seven districts in Florida and four districts in Connecticut. Temporal characteristics include time of day, day of the week, and month of the year. Environmental characteristics include factors such as weather and lighting conditions. Vehicular characteristics included the type of vehicles and the age of vehicles at the time of the crash. Crash characteristics include the location of harmful events. Roadway characteristics include surface condition, roadway alignment, median barrier, and functional class of roadways. Finally, driver characteristics include gender, age, driving condition, speeding behavior, DUI (Driving Under the Influence), and restraint usage information.

Fig. 1 illustrates the crashes by driver injury levels[3] for each year during the analysis period, from 2015 to 2018. Interestingly, Florida's cellphone-related distracted driving crashes showed a descending trend[4] in recent years, while Connecticut's crashes showed an increasing trend[5] during the same period.

Fig. 2 shows the aggregate driver injury severity over the four years. In Florida, severe driver injury accounts for 4% (132), minor injury 27% (1002), and no injury 69% (2579) of total cellphone-related crashes. On the other hand, in Connecticut, severe driver injury accounts for 1% (14), minor injury 29% (282), and no injury 70% (688) of total cellphone-related crashes. It is important to note that severe injury in Florida was 9.4 times, minor injury 3.6 times, and no injury 3.7 times higher than those in Connecticut.[6]

Table 2 presents descriptive statistics (mean and standard deviation) of all the statistically significant variables in the two models.[7]

4. Methodology

In this study, a random parameter multinomial logit model that accounts for possible heterogeneity in the means and variances of the random parameters has been utilized to address the possible unobserved heterogeneity[8] in the single-vehicle cellphone-related crash data. The injury severity of drivers in single-vehicle cell-phone distraction in Florida and Connecticut is considered with possible injury outcomes of no injury, minor injury (possible injury and non-incapacitating injury), and severe injury (incapacitating injury and fatality). The modeling approach starts by defining a function that determines injury severity,

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

where S_{in} is an injury-severity function determining the probability of injury-severity outcome i in single-vehicle crash n, $\boldsymbol{X}_{in}$ is a vector of explanatory variables that affect single-vehicle cellphone distracted crash injury-severity level i, $\boldsymbol{\beta}_i$ is a vector of estimable parameters, and ε_{in} is the error term. If this error term is assumed to be generalized extreme value distributed, a standard multinomial logit model results as McFadden (1981):

$$P_n(i) = \frac{EXP[\boldsymbol{\beta}_i \boldsymbol{X}_{in}]}{\sum_{\forall I} EXP[\boldsymbol{\beta}_i \boldsymbol{X}_{in}]}$$

where $P_n(i)$ is the probability that a single-vehicle cellphone distracted crash n will result in driver-injury severity outcome i and I is the set of the three injury-severity outcomes. The following form of Equation 2 allows for the possibility of one or more parameter estimates in the vector $\boldsymbol{\beta}_i$ to vary across each crash (i.e., each observation) (Washington et al., 2012):

$$P_n(i) = \int \frac{EXP(\boldsymbol{\beta}_i \boldsymbol{X}_{in})}{\sum_{\forall I} EXP(\boldsymbol{\beta}_i \boldsymbol{X}_{in})} f(\boldsymbol{\beta}_i|\boldsymbol{\varphi}_i) d\boldsymbol{\beta}_i$$

where $f(\boldsymbol{\beta}_i|\boldsymbol{\varphi}_i)$ is the density function of $\boldsymbol{\beta}_i$ and $\boldsymbol{\varphi}_i$ is a vector of parameters describing the density function (mean and variance), and all other terms are as previously defined.

To account for the possibility of unobserved heterogeneity in the means and variances of parameters, let $\boldsymbol{\beta}_{in}$ be a vector of estimable parameters that varies across single-vehicle cell-phone distracted crashes defined as (a similar formulation used by Islam, 2024a; Islam, 2024b; Islam, 2023; Islam & Bertini, 2023; Islam et al., 2023, Islam & Mannering, 2020; Islam & Mannering, 2021; Islam, 2021; Islam, 2022a; Islam 2022b; Islam, 2023; Islam et al., 2020; Islam & Pande, 2020) in other injury severity contexts.

$$\boldsymbol{\beta}_{in} = \beta_i + \Theta_{in} \boldsymbol{Z}_{in} + \sigma_{in} EXP(\psi_{in} \boldsymbol{W}_{in}) \nu_{in} \tag{4}$$

where β_i is the mean parameter estimate across all single-vehicle truck crashes, $\boldsymbol{Z}_{in}$ is a vector of crash-specific explanatory variables that captures heterogeneity in the mean that affects injury-severity level i, $\boldsymbol{\Theta}_{in}$ is a corresponding vector of estimable parameters, $\boldsymbol{W}_{in}$ is a vector of crash-specific explanatory variables that captures heterogeneity in the standard deviation σ_{in} with corresponding parameter vector Ψ_{in}, and ν_{in} is a disturbance term.

During model estimation, several density functions (e.g., uniform, triangular, log-normal, Weibull) were empirically evaluated for the term $f(\boldsymbol{\beta}_i|\boldsymbol{\varphi}_i)$. However, normal distribution was found to be statistically superior to all and was used in model estimation (this finding is consistent with past work including Islam, 2024a; Islam, 2024b; Islam, 2023; Islam & Bertini, 2023; Islam et al., 2023; Islam & Mannering, 2020; Islam & Mannering, 2021; Islam, 2021; Islam & Mannering, 2023; Islam, 2022a; Islam, 2022b; Islam et al., 2020; Islam & Pande, 2020). The model estimations used simulated maximum likelihood with 1,000 Halton draws (Train, 2009; McFadden & Train, 2000; Bhat, 2001). Marginal effects are estimated to determine the effect of explanatory variables on injury severity probabilities. The marginal effect provides the effect that a one-unit increase (or presence of indicator variable from '0' to '1') in an explanatory variable has on the injury-outcome probabilities.

To test for differences in injury severity for two geographic areas, such as Florida and Connecticut further, additional likelihood ratio tests could be considered to run as (Washington et al.,2012),

$$X^2 = -2[LL(\beta_{FL,CT}) - LL(\beta_{CT})] \tag{5}$$

$$X^2 = -2[LL(\beta_{CT,FL}) - LL(\beta_{FL})] \tag{6}$$

[3] The frequency and proportion of driver severe injury in Connecticut is much lower than those in Florida. This frequency needs to be considered if temporal instability is a critical issue for Connecticut crash data for individual years. As such, temporal instability is not within the scope of this current study.

[4] This is because there were 986 crashes in 2015, 965 crashes in 2016, 896 crashes in 2017, and 866 crashes in 2018 in Florida.

[5] While there were 216 crashes in 2015, 248 crashes in 2016, 275 crashes in 2017, and 245 crashes in 2018 in Connecticut.

[6] Considering the comparative frequency of driver injury severity, the ban on cell phone usage while driving was much more controlled in Connecticut compared to that in Florida. However, this study investigated into the severity analysis where more in-depth insights were provided (see details in Estimated Model Results and Discussion).

[7] There were more than the variables listed in Table 2 considered for the model estimation process. Providing the descriptive statistics of all those variables, that were not statistically significant, were out of the scope of this current study.

[8] An alternative approach would be an ordered probability model to account for the ordering of crash-injury severities (Washington et al., 2020). However, standard-ordered probability models pose an often-unrealistic restriction that excludes the possibility of an explanatory variable simultaneously increasing (or decreasing) high and low injury severity levels (see Mannering & Bhat, 2014). Extensions of standard ordered probability models to resolve this issue, such as the mixed generalized ordered response model, can also be problematic because of complications due to non-decreasing threshold variances.

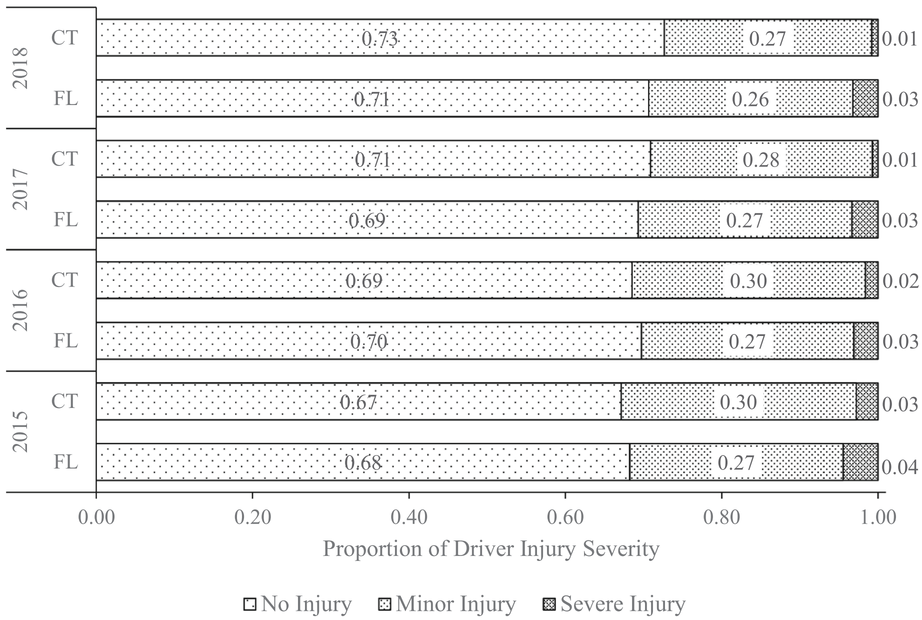

Fig. 1. Driver Injury Severity Proportion due to Cell-Distraction in Florida (FL) and Connecticut (CT) over the Analysis Period: 2015–18.

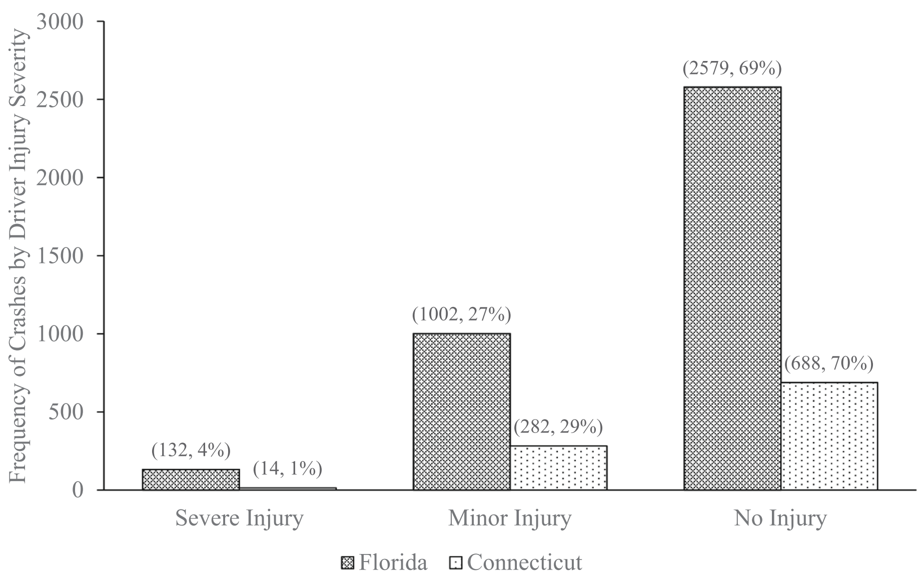

Fig. 2. Comparison of Driver Injury Severity due to Cell-Distraction in Florida (FL) and Connecticut (CT): 2015–18.

where $LL(\boldsymbol{\beta}_{FL,\ CT})$ is the log-likelihood at the convergence of a model containing converged parameters based on using Connecticut data while using data from Florida data, and $LL(\boldsymbol{\beta}_{CT})$ is the log-likelihood at the convergence of the model using Connecticut data, with parameters no longer restricted to using Connecticut converged parameters as is the case for $LL(\boldsymbol{\beta}_{FL,\ CT})$.

5. Estimated model results and discussion

Since few variables are unique to Florida crash data (e.g., speeding with 10 mi/hr over the posted speed limit, driver violation history, FDOT District 5) and Connecticut data (e.g., speeding) not present in Connecticut data and vice versa, Eq (5) and Eq (6) would not yield a convergent model with a definite log-likelihood value (function). To perform a transferability test and an out-of-sample test between these two states' crash data, it would not yield a convergent model because some of the data (or the variables) is unique to Connecticut and Florida. As such, it is clear from the crash data (see Table 2 and 5[9,10]) only four variables are common, and the rest are not common to both state's crash data.

Tables 3, 4, and 5 present the estimated model results for Florida, and Connecticut, and the marginal effects of these two models, respectively.

5.1. Random parameters

In the Florida model, the constant specific to minor injury was found

[9] Some of the variables are only present in Florida, but not in Connecticut.
[10] Only shaded variables are common between Florida and Connecticut.

Table 2
Descriptive statistics of key variables in the driver injury severity models in florida and connecticut.

	Florida		Connecticut	
	Mean	Std. Dev.	Mean	Std. Dev.
Spatial characteristics				
FDOT District 5 indicator (1 if the crash occurred in FDOT District 5, 0 otherwise)	0.198	0.399	–	–
Environmental characteristics				
Adverse weather indicator (1 if the crash occurred during the adverse weather (cloudy and rainy conditions), 0 otherwise)	0.180	0.384	0.125	0.330
Traffic characteristics				
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	0.228	0.419	0.648	0.477
Vehicular characteristics				
Passenger car indicator (1 if passenger car, 0 otherwise)	0.624	0.484	0.678	0.466
Newer vehicle indicator (1 if the crash occurred in less than 5 years from vehicle manufactured, 0 otherwise)	0.287	0.452	0.262	0.439
Roadway characteristics				
Wet surface indicator (1 if the crash occurred on the wet surface of the roadways, 0 otherwise)	0.107	0.309	0.144	0.351
Curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	0.223	0.416	0.292	0.455
Roadway with positive median barrier indicator (1 if the crash occurred at roadways with the positive median barrier, 0 otherwise)	0.288	0.452	0.141	0.348
Urban interstate indicator (1 if crashes occurred on urban interstate, 0 otherwise)	0.036	0.188	0.063	0.243
Crash characteristics				
−Harmful non-fixed object indicator (1 if the harmful event occurred with non-fixed object, 0 otherwise)	0.257	0.437	0.024	0.154
Harmful event off-road indicator (1 if the harmful event occurred off-road, 0 otherwise)	0.444	0.496	0.058	0.235
Harmful event at shoulder indicator (1 if shoulder was harmful event, 0 otherwise)	0.148	0.356	0.221	0.414
Driver characteristics				
Male driver indicator (1 if the driver was male, 0 otherwise)	0.582	0.493	0.595	0.491
Female driver indicator (1 if driver was female, 0 otherwise)	0.411	0.492	0.384	0.486
Young aged driver indicator (1 if driver age is below 30 years, 0 otherwise)	0.302	0.459	0.551	0.497
Middle-aged distracted diver indicator (1 if the driver aged between 30 to 49 years old was distracted by phone, 0 otherwise)	0.307	0.461	0.131	0.337
Normal driving indicator (1 if normal driving was involved, 0 otherwise)	0.786	0.409	0.734	0.441
Texting while using cellphone indicator (1 if the driver was texting while on cellphone, 0 otherwise)	0.060	0.238	0.802	0.397
Driving under the influence indicator (1 if the driver was driving under the influence, 0 otherwise)	0.098	0.298	0.155	0.362
Middle-age cellphone distracted diver indicator (1 if drivers aged between 30 to 49 years old were distracted, 0 otherwise)	0.307	0.461	0.049	0.217
Middle-aged driver texting indicator (1 if drivers of age between 30 to 49 years were involved in text while using cellphone, 0 otherwise)	0.021	0.144	0.261	0.439
Careless driving indicator (1 if careless driving was involved, 0 otherwise)	0.569	0.495	–	–
Exceeding the speed limit by more than 10 mi/hr indicator (1 if the travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	0.096	0.295	–	–
Driving slower than the speed limit by more than 10 mi/h indicator (1 if travel speed was slower than the speed limit by more than 10 mi/hr, 0 otherwise)	0.127	0.333	–	–
Driving violation indicator (1 if the driver had a previous violation history, 0 otherwise)	0.590	0.492	–	–
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise)	0.888	0.317	0.808	0.393

Std. Dev. = Standard Deviation; FDOT = Florida Department of Transportation; "–" represents variables that were not mapped in the CT crash database.

to be a statistically significant random parameter,[11] with a mean of −1.002 and a standard deviation of 4.156. With this mean and standard deviation, the constant is 41.22% more likely to result in a minor injury. Furthermore, the Florida model identified two factors introducing heterogeneity in the mean and variance of the model: young drivers under 30 years of age and travel speeds slower than the speed limit by more than 10 mi/hr. Consequently, an increase in the involvement of young drivers under 30 years old will result in a higher likelihood of minor injury. Conversely, an increase in travel speeds slower than the speed limit by more than 10 mi/hr will lead to a lower likelihood of minor injury.

Turning to the Connecticut model, speeding behavior was found to be a statistically significant random parameter, with a mean of 3.333 and a standard deviation of 5.413. With this mean and standard deviation, speeding behavior is 76.99% more likely to result in no injury. In the Connecticut model, two additional factors were found to introduce heterogeneity in the mean and variance of the model: texting operation while driving and driving on straight roadway sections. An increase in texting operation while driving will result in a lower likelihood of no injury (or a higher likelihood of injury crashes). Similarly, an increase in driving on straight roadway sections will lead to a lower likelihood of no injury (or a higher likelihood of injury crashes).

5.2. Driving behavior and driver characteristics

5.2.1. Driver's gender

In Florida, male drivers were involved in crashes with a 0.0019 higher probability of severe injury due to cellphone usage while driving. In contrast, Connecticut female drivers were involved in crashes with a 0.0013 lower likelihood of severe injury and a 0.0211 higher probability of minor injury due to cellphone usage while driving. These differences could be attributed to the findings of Li et al. (2016), which suggest that females tend to maintain a larger safety margin with the leading vehicle compared to males when using cellphones while driving. Moreover, the difference in vehicle control and attentiveness between genders may contribute to these variations in injury probabilities. Male drivers might be more confident in their vehicle control while using cellphones, possibly leading to a higher likelihood of severe injury crashes, while

[11] Driver's risk in the form of driving under the influence, a previous violation history, and careless driving could lead to distracted driving crashes resulting in different levels of injuries. Although there is a possibility that the presence of endogeneity influences driver perception and crash severity, heterogeneity models, such as mixed logit with heterogeneity in means and variances capture some of that effect. For example, for the Florida model, the random parameter was constant and specific to a minor injury, and which mean of the random parameter was young drivers (below 30 years of age) and the variance was driving slower than the speed limit by more than 10 mi/hr. These driving behaviors reflect some unobserved factors that might not have been collected by the police officers in Florida.

Table 3
Model Results of Random Parameter Multinomial Logit for Driver Injury Severity in Single-vehicle Crashes involving Distracted Driving with Cellphone in Florida (2015–18).

	Parameter Estimates		Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	−1.543	−5.84			
Random parameter (normally distributed)					
Constant [MI]	−1.002	−2.13			
(*standard deviation of parameter distribution*)	*(4.516)*	*(5.48)*			
Heterogeneity in the mean of random parameter					
Constant: Young driver indicator (1 if driver age below 30 years, 0 otherwise) [MI]	0.550	2.40			
Heterogeneity in the variance of random parameter					
Constant: Driving slower than the speed limit by more than 10 mi/hr indicator (1 if travel speed was slower than the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	−0.384	−3.12			
Spatial characteristics					
FDOT District 5 indicator (1 if crash occurred in FDOT District 5, 0 otherwise) [SI]	0.544	2.53	−0.0040	−0.0006	0.0046
Environmental characteristics					
Adverse weather indicator (1 if crash occurred during the adverse weather (cloudy and rainy condition, 0 otherwise) [SI]	0.448	2.01	−0.0029	−0.0005	0.0033
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/ day, 0 otherwise) [NI]	−0.629	−3.69	−0.0146	0.0096	0.0050
Vehicular characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise) [SI]	−0.367	−1.87	0.0052	0.0008	−0.0060
Newer vehicle indicator (1 if crash occurred in less than 5 years from vehicle manufactured, 0 otherwise) [MI]	−0.644	−2.46	0.0109	−0.0115	0.0006
Roadway characteristics					
Wet surface indicator (1 if crash occurred on wet surface of the roadways, 0 otherwise) [MI]	0.734	2.13	−0.0053	0.0058	−0.0005
Curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.404	1.89	−0.0030	−0.0005	0.0035
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise) [NI]	−0.443	−2.66	−0.124	0.0084	0.0040
Crash characteristics					
Harmful non-fixed object indicator (1 if the harmful event occurred with non-fixed object, 0 otherwise) [MI]	−1.588	−4.29	0.0207	−0.0218	0.0012
Harmful event off-road indicator (1 if harmful event occurred off-road, 0 otherwise) [NI]	−0.475	−2.98	−0.0202	0.0138	0.0064
Harmful event at shoulder indicator (1 if shoulder was harmful event, 0 otherwise) [MI]	0.528	1.73	−0.0054	0.0057	−0.0003
Driver characteristics					
Male driver indicator (1 if the driver was male, 0 otherwise) [MI]	−0.903	−3.57	0.0319	−0.0338	0.0019
Young aged driver indicator (1 if driver age was below 30 years, 0 otherwise) [SI]	−0.583	−2.39	0.0040	0.0006	−0.0046
Middle-aged distracted diver indicator (1 if the driver aged between 30 to 49 years old was distracted with phone operation, 0 otherwise) [SI]	−0.549	−2.39	0.0040	0.0005	−0.0046
Careless driving indicator (1 if careless driving was involved, 0 otherwise) [MI]	0.489	2.16	−0.0184	0.0194	−0.0011
Exceeding the speed limit by more than 10 mi/hr indicator (1 if travel speed exceededthe speed limit by more than 10 mi/hr, 0 otherwise) [NI]	−0.985	−4.40	−0.0105	0.0062	0.0043
Driving violation indicator (1 if the driver had a	0.476	3.14	0.0242	−0.0178	−0.0064

(*continued on next page*)

Table 3 (*continued*)

	Parameter Estimates		Marginal Effects		
			No Injury	Minor Injury	Severe Injury
previous violation history, 0 otherwise) [NI]					
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	2.054	10.50	0.1529	−0.1155	−0.0374
Number of observations	3733				
Log-likelihood at zero	−4101.119				
Log-likelihood at convergence	−2533.659				
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$	0.382				

SI = Severe Injury; MI = Minor Injury; NI = No Injury; FDOT = Florida Department of Transportation

female drivers may exhibit higher attentiveness while using cellphones, contributing to a higher probability of minor injury crashes.

5.2.2. Driver's age

Young Drivers: For young drivers under 30 years old, the probability of minor injury was higher in both states, with a 0.0006 increase in Florida and a 0.0020 increase in Connecticut. This suggests that Connecticut's young drivers involved in cellphone use crashes were 3.3 times more likely to experience minor injuries than young drivers in Florida (see Fig. 3). This difference can be further explained by the percentage of young drivers involved in cellphone distracted driving crashes in each state, with 30.2% in Florida and 55.1% in Connecticut.

Middle-aged Drivers: Connecticut middle-aged drivers between 30 to 49 years old had a 0.0018 higher probability of severe injury in crashes involving texting on cellphones. On the other hand, Florida middle-aged drivers in the same age range had a 0.0046 lower probability of severe injury when attempting to use cellphones.

5.2.3. Risky driving behaviors

Florida drivers involved in crashes with careless driving had a 0.0194 higher probability of minor injury. Conversely, Connecticut drivers involved in crashes due to driving under the influence had a 0.0143 higher probability of minor injury. Additionally, Connecticut drivers involved in crashes due to speeding had a 0.0005 higher probability of severe injury, whereas Florida drivers had a 0.0043 higher probability of severe injury when speeding over 10 mi/hr above the posted speed limit. This result aligns with the findings of Doucette et al. (2021), indicating that speeding is more prevalent among other risky driving behaviors in Connecticut and is a contributing factor to the increased occurrence of fatal vehicle crashes in the state.

5.2.4. Seatbelt usage

Restrained drivers had a 0.0374 lower probability of severe injury in Florida and a 0.0032 lower probability of severe injury in Connecticut. This suggests that Florida drivers who were restrained and involved in crashes while using cellphones were 11.7 times less likely to experience severe injury than Connecticut drivers (see Fig. 4). This can be further explained by noting that in Florida, drivers involved in crashes were 88.8% restrained, whereas Connecticut drivers were 80.8% restrained. This result is consistent with the finding by Rahman et al. (2023), which indicated a strong association between non-usage of restraints and fatal and severe injuries in cellphone use-related crashes.

Table 4
Model Results of Random Parameter Multinomial Logit for Driver Injury Severity in Single-vehicle Crashes Involving Distracted Driving with Cellphone in Connecticut (2015–18).

s	Parameter Estimates		Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	−1.793	−2.31			
Constant [MI]	−0.319	−1.69			
Random parameter (normally distributed)					
Speeding indicator (1 if the driver was speeding, 0 otherwise) [NI] (*standard deviation of parameter distribution*)	3.333 *(5.413)*	1.78 *(1.85)*	−0.0160	0.0155	0.0005
Heterogeneity in the mean of random parameter					
Speeding indicator (1 if the driver was speeding, 0 otherwise): Texting indicator (1 if the driver was engaged in cellphone texting, 0 otherwise) [NI]	−1.732	−1.80			
Heterogeneity in the variance of random parameter					
Speeding indicator (1 if the driver was speeding, 0 otherwise): Straight section indicator (1 if the subject roadway section was straight, 0 otherwise) [NI]	−0.399	−1.63			
Temporal characteristics					
Afternoon non-peak indicator (1 if the crash occurred between 1 and 3 PM, 0 otherwise) [NI]	−0.671	−2.19	−0.0125	0.0120	0.0005
Vehicular characteristics					
Newer vehicle indicator (1 if the crash occurred in less than 5 years from vehicle manufactured, 0 otherwise) [MI]	−0.416	−1.64	0.0111	−0.0122	0.0010
Roadway characteristics					
Urban interstate indicator (1 if crashes occurred on urban interstate, 0 otherwise) [NI]	−1.155	−2.68	−0.0106	0.0101	0.0005
Crash characteristics					
Harmful event at shoulder indicator (1 if shoulder was harmful event, 0 otherwise) [SI]	1.934	2.66	−0.0070	−0.0081	0.0151
Driver characteristics					

(*continued on next page*)

Table 4 (*continued*)

s	Parameter Estimates		Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Female driver indicator (1 if the driver was female, 0 otherwise) [MI]	0.432	1.99	−0.0199	0.0211	−0.0013
Young aged driver indicator (1 if driver age was below 30 years, 0 otherwise) [SI]	−0.681	−1.63	0.0015	0.0020	−0.0034
Normal driving indicator (1 if normal driving was involved, 0 otherwise) [SI]	−1.673	−2.37	0.0042	0.0056	−0.0099
Texting while using cellphone indicator (1 if the driver was texting while on cellphone, 0 otherwise) [SI]	−1.377	−2.00	0.0052	0.0067	−0.0119
Driving under influence indicator (1 if driver was driving under the influence, 0 otherwise) [MI]	0.614	2.25	−0.0128	0.0143	−0.0014
Middle-aged driver texting indicator (1 if drivers of age between 30 to 49 years wereinvolved in the text while using a cellphone, 0 otherwise) [MI]	−0.791	−2.79	0.0015	−0.020	0.0018
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	0.737	2.76	0.0679	−0.0646	−0.0032
Number of observations	984				
Log-likelihood at zero	−1081.034				
Log-likelihood at convergence	−621.072				
$\rho^2 = 1 - LL(\beta)/LL(0)$	0.425				

SI = Severe Injury; MI = Minor Injury; NI = No Injury.

5.3. Other characteristics

5.3.1. Spatial characteristics

In Florida's District 5,[12] drivers experienced a 0.0046 increased probability of severe injury crashes due to cellphone usage, possibly influenced by higher traffic density and road conditions. In contrast, no significant relationship was observed in any districts in Connecticut, suggesting potential regional variations in the impact of cellphone usage on severe injury crashes.

5.3.2. Temporal characteristics

Connecticut drivers driving between 1p.m. and 3p.m. had a 0.0005 higher probability of severe injury and a 0.0120 higher probability of minor injury crashes due to cellphone usage. This increased probability can be attributed to higher speeds during off-peak hours, leading to higher crash severity. This result aligns with the study by Islam (2024a), which also reported a considerable positive impact on crash severity involving distracted driving during off-peak hours. Interestingly, this variable did not show statistical significance in Florida, highlighting potential regional variations in the impact of time-dependent factors on road safety.

5.3.3. Environmental characteristics

Florida drivers driving in adverse weather conditions, including rainy and cloudy weather, were found to have a 0.0033 higher probability of severe injury due to cellphone usage. This finding aligns with the study conducted by Islam et al. (2023), as they also reported that adverse weather conditions, such as rain, increase the probability of minor injury due to distracted driving crashes. Interestingly, this variable was not statistically significant in Connecticut.

5.3.4. Traffic characteristics

In Florida, drivers operating in traffic conditions of less than 40,000 vehicles per day had a 0.0055 higher probability of severe and a 0.0096 higher probability of minor injury crashes due to cellphone usage. This might be because, in low-traffic situations, drivers might perceive a reduced risk of collisions and consequently engage in more distracted behaviors, such as using cellphones, leading to higher chances of severe and minor injury crashes. This result is consistent with findings of Hasan et al. (2022), which indicated that higher annual average daily traffic (AADT) levels reduce injury severity of distracted driving crashes. Notably, this variable did not show statistical significance in Connecticut.

5.3.5. Vehicular characteristics

In Florida, drivers operating passenger cars had a 0.0060 lower probability of severe, but a 0.0008 higher probability of minor injury crashes related to cellphone usage while driving. Additionally, drivers using new vehicles manufactured less than five years before their crash involvement had a 0.0006 higher probability of severe injury in Florida and a 0.0010 higher probability of severe injury in Connecticut. This suggests that Connecticut drivers involved in cellphone-related crashes were 1.7 times more likely to experience severe injuries compared to Florida drivers (see Fig. 5). These results could potentially be attributed to the presence of a higher population of sport utility vehicles (SUVs) in Connecticut compared to Florida. SUVs, with their larger size and higher center of gravity compared to passenger cars, may contribute to more severe crash outcomes, potentially explaining the higher probability of severe injuries in Connecticut. This result is consistent with the findings of Rahman et al. (2021), which revealed that compared to passenger car drivers, those operating SUVs were more frequently observed to be involved in talking/texting. Fig. 3 shows the variation in the probability of injury severity for Connecticut and Florida drivers.

5.3.6. Roadway characteristics

In Florida, cellphone usage while driving on wet road surfaces increased the probability of minor injury crashes by 0.0058. On curved roadways, the probability of severe injury crashes increased by 0.0035. Additionally, driving on roads with a positive median barrier raised the probability of severe injury by 0.0040 and minor injury by 0.0084. These findings are supported by Lugo Kuzy et al. (2021) and Goswamy et al. (2023), who found that positive median barriers increase crash severity, and by Lym and Chen (2021), who reported that curved roads exacerbate driver injury severity in distracted driving crashes.

In Connecticut, cellphone usage while driving on urban interstate highways increased the probability of severe injury crashes by 0.0005, consistent with the findings of Hasan et al. (2022) and Chen and Lym (2021), who indicated higher severity for distracted driving crashes on interstate highways.

[12] Florida District 5 defined by the Florida Department of Transportation includes Daytona Beach, DeLand, Melbourne, Merritt Island, Ocala, Orlando, and Titusville.

Table 5
Comparison of Marginal Effects of Driver Injuries on Cellphone Distracted Drivers in Florida and Connecticut (variables common in both models were shaded).

Variables	No Injury		Minor Injury		Severe Injury	
	Connecticut	Florida	Connecticut	Florida	Connecticut	Florida
Spatial characteristics						
FDOT District 5 indicator (1 if the crash occurred in FDOTDistrict 5, 0 otherwise)	–	−0.0040	–	−0.0006	–	0.0046
Temporal characteristics						
Afternoon non-peak indicator (1 if the crash occurred between1 to 3 PM, 0 otherwise)	−0.0125	–	0.0120	–	0.0005	–
Environmental characteristics						
Adverse weather indicator (1 if the crash occurred during theadverse weather (cloudy and rainy conditions, 0 otherwise)	–	−0.0029	–	−0.0005	–	0.0033
Traffic characteristics						
Low traffic condition indicator (1 if average annual dailytraffic (AADT) is below 40,000 vehicles/day, 0 otherwise)	–	−0.0146	–	0.0096	–	0.0050
Vehicular characteristics						
Passenger car indicator (1 if passenger car, 0 otherwise)	–	0.0052	–	0.0008	–	−0.0060
Newer vehicle indicator (1 if the crash occurred in less than 5years from the vehicle manufactured, 0 otherwise)	0.0111	0.0109	−0.0122	−0.0115	0.0010	0.0006
Roadway characteristics						
Wet surface indicator (1 if the crash occurred on the wet surface of the roadways, otherwise)	–	−0.0053	–	0.0058	–	−0.0005
Curved segment indicator (1 if roadway curves to the left or right of travel direction, 0 otherwise)	–	−0.0030	–	−0.0005	–	0.0035
Roadway with positive median barrier indicator (1 if the crash occurred at roadways with the positive median barrier, 0otherwise)	–	−0.0124	–	0.0084	–	0.0040
Urban interstate indicator (1 if crashes occurred on urbaninterstate, 0 otherwise)	−0.0106	–	0.0101	–	0.0005	–
Crash characteristics						
Harmful non-fixed object indicator (1 if the harmful eventoccurred with the non-fixed object, 0 otherwise)	–	0.0207	–	−0.0218	–	0.0012
Harmful event off-road indicator (1 if harmful eventoccurred off-road, 0 otherwise)	–	−0.0202	–	0.0138	–	0.0064
The harmful event at the shoulder indicator (1 if the shoulder was a harmful event, 0 otherwise)	−0.0070	−0.0054	−0.0081	0.0057	0.0151	−0.0003
Driver characteristics						
Male driver indicator (1 if the driver was male, 0 otherwise)	–	0.0319	–	−0.0338	–	0.0019
Female driver indicator (1 if driver was female, 0 otherwise)	−0.0199	–	0.0211	–	−0.0013	–
Young aged driver indicator (1 if the driver's age was below 30 years, 0 otherwise)	0.0015	0.0040	0.0020	0.0006	−0.0034	−0.0046
Normal driving indicator (1 if normal driving was involved,0 otherwise)	0.0042	–	0.0056	–	−0.0099	–
Texting while using cellphone indicator (1 if the driver wastexting while on a cellphone, 0 otherwise)	0.0052	–	0.0067	–	−0.0119	–
Middle-age cellphone distracted diver indicator (1 if the driver aged between 30 to 49 years old was distracted withoperating cellphone, 0 otherwise)	–	0.0040	–	0.0005	–	−0.0046
Middle-aged driver texting indicator (1 if the driver is of age between 30 to 49 years were involved in text while usingcellphone, 0 otherwise)	0.0015	–	−0.020	–	0.0018	–
Driving under the influence indicator (1 if the driver was drivingunder the influence, 0 otherwise)	−0.0128	–	0.0143	–	−0.0014	–
Careless driving indicator (1 if careless driving was involved, 0 otherwise)	–	−0.0184	–	0.0194	–	−0.0011
Speeding indicator (1 if the driver was speeding, 0 otherwise)	−0.0160	–	0.0155	–	0.0005	–
Exceeding the speed limit by more than 10 mi/hr indicator (1if travel speed exceeded the speed limit by more than 10mi/hr, 0 otherwise)	–	−0.0105	–	0.0062	–	0.0043
Driving violation indicator (1 if the driver had a previous violation history, 0 otherwise)	–	0.0242	–	−0.0178	–	−0.0064
Restraint usage indicator (1 if shoulder and lap belt used, 0otherwise)	0.0679	0.1529	−0.0646	−0.1155	−0.0032	−0.0374

FDOT = Florida Department of Transportation; "–" represents variables that were not found statistically significant in either of the state's crash database.

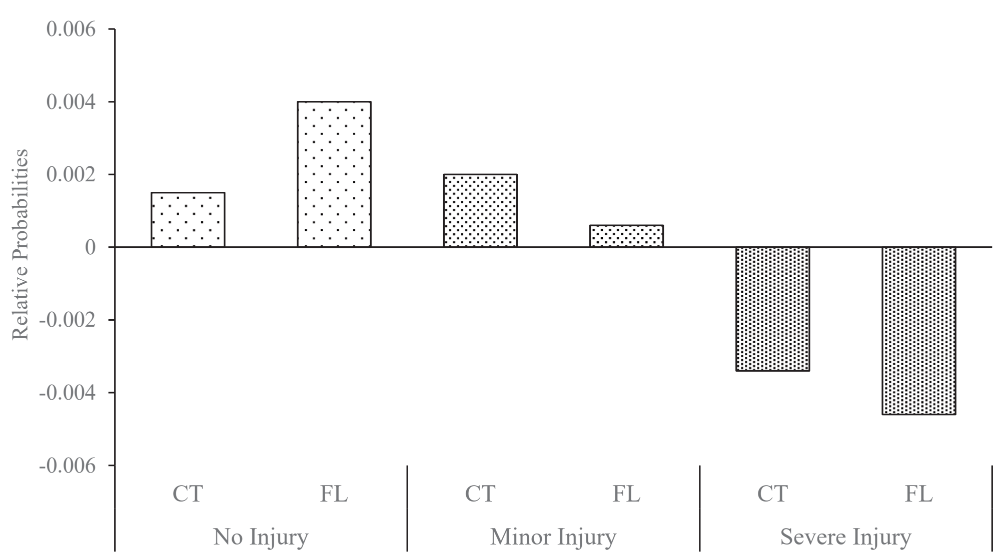

Fig. 3. Effect of Driver Age Less than 30 Years on the Driver Injury Severity Due to Cellphone Usage in Connecticut (CT) and Florida (FL).

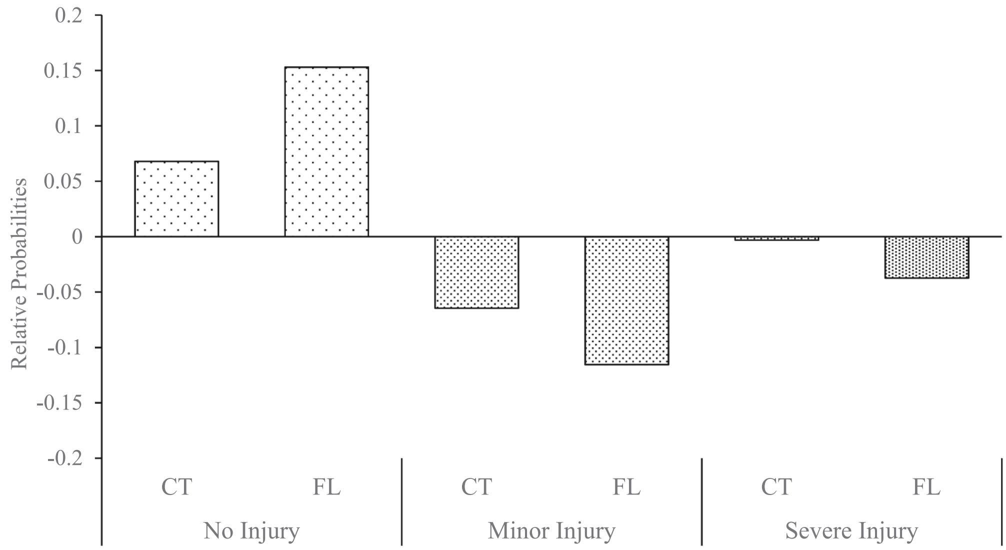

Fig. 4. Effect of Restraint on Driver Injury Severity Due to Cellphone Usage in Connecticut (CT) and Florida (FL).

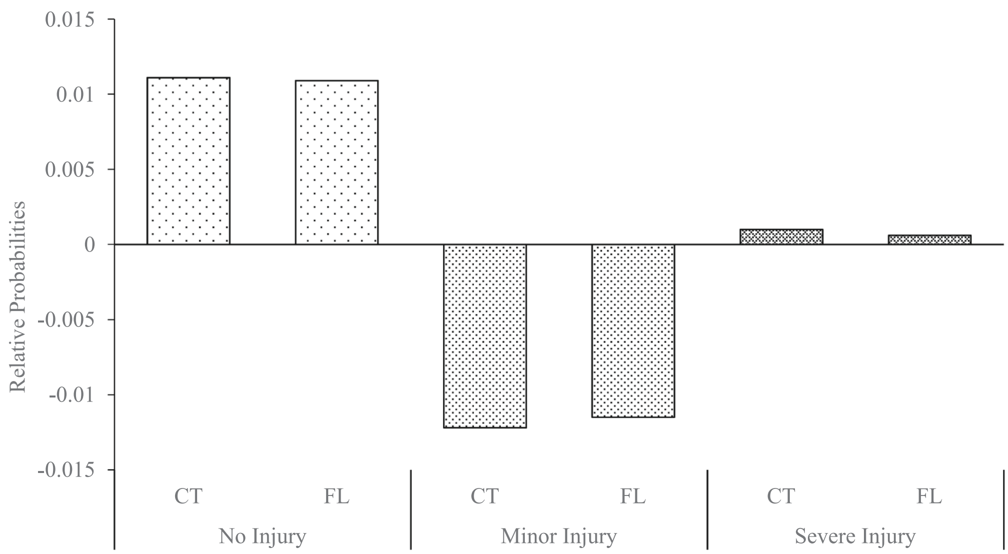

Fig. 5. Effect of Newer Vehicles on Driver Injury Severity Due to Cellphone Usage in Connecticut (CT) and Florida (FL).

5.3.7. Crash characteristics

In Florida, cellphone usage while driving increased the probability of severe injury crashes by 0.0012 when involving non-fixed objects and by 0.0064 for drivers who ran off the road. These drivers also had a 0.0138 higher probability of minor injury crashes. Crashes involving harmful events on the shoulder showed a 0.0003 lower probability of severe injury in Florida but a 0.0151 higher probability in Connecticut (see Fig. 6). This aligns with Hosseinpour et al. (2021), who found that shoulder challenges increase the risk of severe injuries in distracted driving crashes. The contrast between Florida and Connecticut could be due to differences in roadside design and maintenance practices, such as shoulder width, safety edges, and the presence of fixed objects within the clear zone.

6. Summary and conclusion

This study aimed to investigate single-vehicle crashes involving drivers in Florida and Connecticut related to cellphone use during the four years from 2015 to 2018 (inclusive). The severity of driver injuries was categorized as severe (including fatal and incapacitating injuries), minor (non-incapacitating and possible injuries), or no injury. Random parameter multinomial logit models were utilized to analyze these injury levels in both states. The key findings from the results are summarized as follows:

• *Common variables***:** Among the 26 statistically significant variables, four were common to both models: involvement of newer vehicles (less than five years since manufacture), harmful events involving shoulders, young drivers (below 30 years old), and restraint usage. These variables highlight important policy implications:

- o Newer vehicles emphasize the importance of modern safety features and underscore the importance of driver's dependency on safety features rather than their attentiveness to driving.
- o Harmful events involving shoulders indicate improvements in roadside design, such as shoulder width and safety edges.
- o Young Drivers highlight the need for targeted driver training and law enforcement campaigns.
- o Restraint Usage emphasizes the reinforcement of seat belt usage in reducing injury severity.

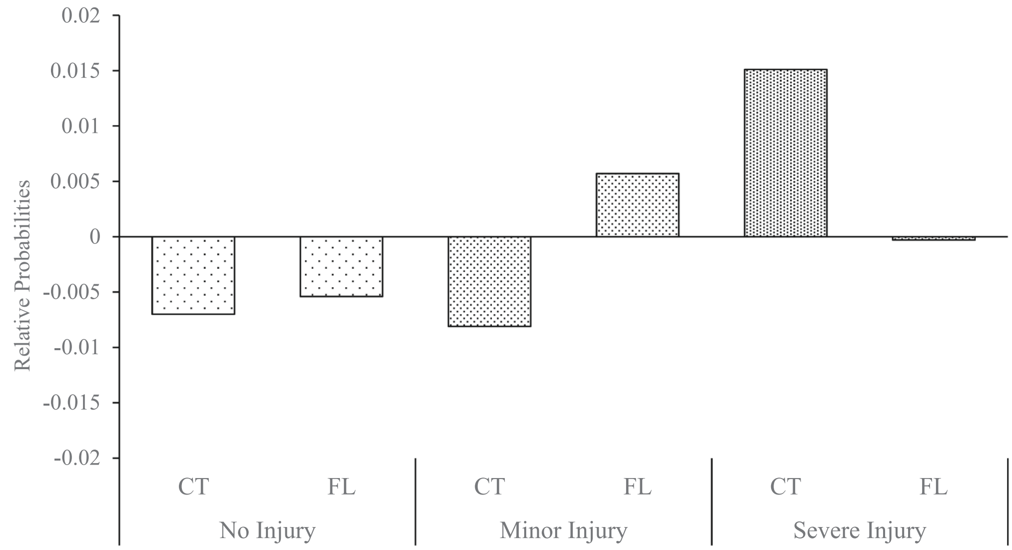

Fig. 6. Effect of Harmful Event at Shoulder on Driver Injury Severity due to Cellphone Usage in Connecticut (CT) and Florida (FL).

• *Differences in state level*: Even though Connecticut experienced a lower crash frequency and injury severity relative to Florida, the risk factors leading to higher injury severity were more prevalent in Connecticut. This highlights the importance of regional characteristics, geography, and weather in understanding crash outcomes.

• *Contextual factors*: Significant differences exist between the two states with the driving behavior, population, roadway characteristics, weather conditions, traffic volume, vehicle miles traveled, vehicle mix, percentage of heavy vehicles, and land use patterns. These factors contribute to the observed differences in crash frequency and severity.

• *Impact of cellphone ban*: Experiencing lower crash frequency and severity in Connecticut suggests some level of effectiveness of the cellphone ban. However, the underlying risk factors indicate that the impact of this ban cannot be fully assessed without considering these variables. The study highlighted the critical role of cellphone usage in driver injury severity using heterogeneity models to account for unobserved factors.

• *Some caveats in study design*: This section acknowledges the limitations of this study to provide context for the findings and identify areas where future research can improve our understanding of driver injury severity in cellphone-related crashes.

o Temporal instability suggests that the estimated parameters may vary from one year to the next. This study did not estimate the heterogeneity models for each year although this was not the major objective of this study. The sample size of crash data by years in Connecticut is also complicated for estimating heterogeneity models. This was not an issue for Florida, which had a relatively larger sample size. This limitation means that the results might not capture year-to-year variations in crash data, which could influence the accuracy of the findings.

o Imbalanced crash data indicates the differences in crash data collection between the two states resulted in inconsistent reporting and collection of crash information. For example, speeding behavior in Connecticut was more subjectively reported, while Florida's data included estimates based on travel speed. Imbalanced crash data can lead to biased results if certain types of crashes or behaviors are underreported or inconsistently recorded. This limitation highlights the need for standardized data collection methods to ensure comparability and accuracy.

o Bias by misspecification suggests the differences in data collection and variable availability (e.g., driver violation history in Florida but not present in Connecticut) could introduce bias. Misspecification bias occurs when the model does not include all relevant variables or inaccurately measures the included variables. This limitation underscores the importance of comprehensive data collection and careful model specification to avoid biased results.

Future studies should focus on technical aspects of model estimations and conduct more refined comparisons of risk factors and their impacts on driver injury severities between the two states. Addressing these methodological limitations can provide more valuable insights into improving road safety measures and policies related to distracted driving caused by cellphone usage.

By focusing on these key findings and acknowledging specific methodological limitations, this study comprehensively analyzed of the factors contributing to driver injury severity in single-vehicle crashes related to cellphone use in Florida and Connecticut. Given the data availability of two states and the advanced statistical modeling approach, this study uncovered the risk factors that led to higher injury severity for Connecticut drivers being higher in magnitude than those for Florida drivers. These higher risk factors are statistically evidenced by common variables found in this study – newer vehicles, harmful events at the right shoulder, young drivers, and restraint usage. Although the effectiveness of the cellphone ban cannot be assessed only focusing on the lower frequency and severity of crashes, the underlying risk factors underscored the importance of cellphone usage among the drivers. This study highlighted the assessment with injury severity-based analysis utilizing heterogeneity models with unobserved factors.

CRediT authorship contribution statement

Mouyid Islam: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Niloufar Shirani:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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