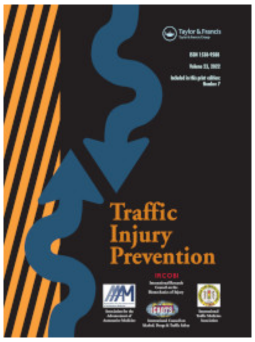

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Cellphone-distracted crashes of novice teen drivers: Understanding associations of contributing factors for crash severity levels and cellphone usage types

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ABSTRACT

Objective: As novice teen drivers are uniquely susceptible to the harmful effects of secondary activities on cellphones, 38 states and Washington D.C. have banned all types of cellphone usage for drivers younger than 18 years or in the learner/intermediate phase of driving. Despite the prevalence of such cellphone prohibitions, several surveillance studies have highlighted the persistent engagement of teenagers in cellphone-distracted driving, which increases the related crash risk. Most of the prior studies broadly consider cellphone usage as a general distraction instead of investigating different distraction-related tasks associated with cellphone use. This study analyzed 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.

Methods: The current study collected five years (2015–2019) of related crash data from the Louisiana Department of Transportation and Development. A manual effort was carried out to recognize the type of cellphone tasks before collision by reading the narratives of police-investigated crash reports. Association rule mining was applied to explore the associations between numerous crash attributes in multiple circumstances without relying on any predetermined hypotheses.

Results: The cumulative effect of cellphone distraction and no seatbelt usage is frequently visible in confirmed injury crash scenarios. Cellphone crashes of novice teenagers at intersections are strongly associated with talking/listening rather than texting/browsing/dialing and reaching for/answering/locating. The associations among environmental factors and modes of cellphone usage significantly influence the manner of collisions. Single-vehicle crashes are associated with cellphone manipulation while driving on weekends in cloudy weather, whereas sideswipe collisions are frequent in evening hours during reaching for/answering/locating the cellphones. In relation to texting/browsing/dialing, novice teenagers operating vans/SUVs are strongly associated with traffic control violations.

Conclusions: The findings are expected to be beneficial for policymakers and other safety officials to develop strategic planning and implementable countermeasures when dealing with cellphone-distracted novice teenagers. The association of factors identified from the analysis exhibits real-world crash scenarios critical to strengthening driver education programs to mitigate teen driver crashes. Moreover, cellphone crashes and related casualties can be reduced by eliminating or improving one of the attributes involved in the crash patterns.

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Introduction

Novice teenagers are uniquely exposed to the harmful effects of secondary activities on cellphones during driving. Therefore, 38 states and Washington D.C. have banned all types of cellphone usage for teen drivers younger than 18 years or in the learner/intermediate phase of driving (Insurance Institute for Highway Safety 2022). Despite the prevalence of such cellphone prohibitions, several surveillance studies have highlighted the persistent engagement of teenagers in cellphone-distracted driving. For example, drivers aged 16 hold a significant share in texting and driving (Tucker et al. 2015), and the percentage of texting during driving increases substantially for 17-year-old teenagers (Li et al. 2018). The possible explanations can be a limited understanding of associated crashes and injuries, lack of conformality among teen drivers, and complexities of law enforcement in real-world settings (Ehsani et al. 2016). Cellphone-involved activities during driving can be more injurious for teenagers due to their inexperience and limited driving skills (Hossain et al. 2022). Moreover, such activities have the potential to draw concentration away from the road, which can reduce headways, increase reaction times, and increase the standard deviation of lateral control (Jannusch et al. 2021).

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Visual-manual tasks on cellphones (e.g., texting/dialing/browsing) impose a much higher risk of crash/near-crash incidence due to longer eye-off glances from the roadway (Farmer et al. 2015). In free-flow traffic, such behavior could increase the probability of rear-end and run-off-road collisions (Owens et al. 2018). Wenners et al. (2013) revealed that female drivers were more frequent in talking/texting. However, the gender-specific variations in cellphone usage can be attributed to time of the day, road geometry, and area setting. For example, Rahman et al. (2021) inferred that in comparison to females, male drivers were observed to manipulate cellphones on urban road segments during peak hours. The association between cellphone usage and unrestrained driving is found to be prevalent, specifically for texting and handheld conversations (Wenners et al. 2013). In relation to passenger presence, drivers are more likely to use cellphones while driving alone than those with passengers (Wenners et al. 2013). Compared to passenger cars, drivers operating sport utility vehicles (SUVs) are more frequently observed to be involved in talking/texting (Rahman et al. 2021). Multiple studies have documented cellphone users' high affiliation with other risky driving behaviors, including speeding, aggressive/careless driving, and disregarding traffic controls (Beck et al. 2007; Atwood et al. 2018; Hossain et al. 2022).

The frequency of cellphone-distracted driving varies by age group. Young drivers have already been emphasized for their prevalence in texting and driving (Atwood et al. 2018). Atchley et al. (2011) surveyed college-aged drivers to provide insights into the patterns and reasons for texting. The study revealed that road lighting, weather, and highway class were significant predictors of initiating texting. Klauer et al. (2014) assessed the correlation between distracted driving and the likelihood of crash/near-crash incidents involving novice teenagers. The authors found that the risk was substantial when dialing a cellphone, followed by reaching for a cellphone and text messaging. To explore other risk-taking behaviors associated with cellphone-distracted driving, Tucker et al. (2015) utilized online safety test data of teenagers for two different periods. While texting, male cellphone users were more likely to be involved in speeding. The findings added that the rate of texting reduced as teen drivers gained more driving experience. Walshe et al. (2018) utilized an updated version of Driving Behavior Questionnaire (DBQ) to specify the associations between cellphone use and young drivers' self-reported experience, including previous citation history and ticketed violations. Consistent with Shaaban et al. (2018), the authors identified prior citation records and traffic violation tendencies as influential factors in talking/texting. Jannusch et al. (2021) employed correspondence analysis on survey responses of 700 young novice drivers and emphasized speeding and intoxicated driving among teenagers who reported talking on cellphones. Hossain et al. (2022) analyzed fatal cellphone crashes of young drivers to explore the grouping of influential factors. The authors identified the combined effects of road and environmental characteristics in related crash scenarios. For instance, fatal crashes in rainy weather on two-way-divided roadways while using cellphones.

Most of the studies have grouped novice motorists into a broad category (e.g., younger than 25 years of age), although newly licensed teenagers have distinct cellphone regulations compared to older drivers. For example, in Louisiana, novice teen drivers (aged 15 to 17 years) are prohibited from talking and texting on a cellphone, whereas only texting during driving is illegal for other driver groups. In addition, those drivers must go through the Graduated Driver Licensing (GDL), which limits their driving access in high-risk situations. The program consists of three stages- learner permit (minimum age: 15, full-time supervised driving), intermediate stage (minimum age: 16, restricted unsupervised driving), and full privilege stage (minimum age: 17). Safety practitioners often want to comprehend the grouping of contributing factors in cellphone-distracted crashes by cellphone usage types to develop more effective and efficient countermeasures. However, majority of the prior studies broadly consider cellphone usage as a general distraction instead of investigating different distraction-related tasks associated with cellphone use. The primary objective of this study is to discover the chains of contributing factors involved in cellphone crashes of novice teen drivers (aged 15–17 years) by crash severity levels and cellphone usage types. Association rule mining (ARM) was used to analyze the related crashes in Louisiana. The generated rules can explain the relationships between crash attributes in multiple circumstances. The association of factors identified from ARM displays real-world crash scenarios critical to future safety improvements and crash reductions, especially for novice teen drivers.

Method

Study data

This study uses five years (2015–2019) of cellphone-distracted crash information from the Louisiana Department of Transportation and Development (LADOTD). A total of 706 cellphone-related crashes occurred in which novice teenagers were reported to be at fault (primary liability holder). Extricating the information regarding the level of liability of other drivers (vehicle 2, 3, etc.) to identify all novice teen drivers involved in multiple-vehicle collisions was found to be unfeasible.

Hard copies of the crash reports were downloaded from the LADOTD database to recognize activities on the cellphone before collision. 64 out of 706 cellphone crashes had no crash report in the database system. In most cases, a police crash report contains narratives, including the responsible police officer's observations and statements from drivers, passengers, or other crash witnesses. In this study, about 85.27% of cellphone crashes had crash reports with narratives. Each narrative was assigned to two reviewers who performed their assessments independently. The reviewers were graduate research assistants with at least two years of research experience using the LADOTD crash database. The feedback of reviewers about cellphone usage type for each

Table 1. Crash report classes in terms of defining cellphone usage types.

Crash report classes	Description from the perspective of defining cellphone usage types
Class 1	Have a clear statement in crash narratives emphasizing the type of cellphone tasks before collision. For example, *"Driver stated she was driving west and looked down to text her father that she was on her way home. She ran off the Rd. and into the ditch"*.
Class 2	Have ambiguous statements about specific tasks on the cellphone before crash occurrence. For instance, *"Driver of vehicle #1 stated that he was Westbound, and he looked at his phone. Vehicle #2 was parked on the side of the road, and vehicle #1 struck vehicle #2 in the rear. Driver of vehicle #1 stated that when he looked back up it was too late, and he could not keep from hitting vehicle #2. Driver of vehicle #1 stated that he was not injured and declined to call for assistance from SFD"*.
Class 3	Have no crash narrative or no statement in narrative regarding cellphone usage

crash observation was matched using unique crash identification numbers. If there was any discrepancy, those crash narratives were further reviewed under supervision of a highway safety expert. Following this process, the collected crash reports can be classified into three groups in terms of defining cellphone usage types (Table 1). By reading the narratives, the reviewers identified 63.55% of crash reports as class 1, 22.27% as class 2, and 14.18% as class 3. "cellphone usage" variable was categorized as unknown for crashes with class 2 and class 3 reports. For the remaining crashes, the recognized cellphone tasks were grouped into four categories (talking/listening, texting/browsing/dialing, reaching for/answering/locating, and navigating) based on one previous cellphone study (Owens et al. 2018). The analytical framework of this study has been displayed in the Appendix section (Figure A1).

The crash contributory factors were selected based on previous studies, engineering judgments, and the availability of variables in the original crash database. The final dataset contains the following sixteen variables.

- Driver characteristics: age, gender, cellphone usage, no seatbelt usage, number of passengers, violation, vehicle type
- Environmental characteristics: crash time, day of the week, lighting condition, weather,
- Road characteristics: road type, road geometry
- Crash characteristics: crash type, movement prior to crash, crash severity

In the "cellphone usage" variable, about 21.53% of novice teenagers were engaged in texting/browsing/dialing, 19.69% were in reaching for/answering/locating, 10.48% were in talking/listening, and 6.09% were in navigating. About 42.21% of crashes had no information on cellphone usage types. In the final dataset, "day of the week" was categorized following the NHTSA classification (weekday: Monday 6:00 am to Friday 5:59 pm, and weekend: Friday 6:00 pm to Monday 5:59 am). The frequency of cellphone crashes by crash severity (most serious injury sustained by any individual involved in the collision) was- fatal (K): 1, severe (A): 3, moderate (B): 48, complaint (C): 159, and no injury (O): 493. Therefore, "crash severity" was regrouped into two levels: confirmed injury crash (KAB) and possible/no injury crash (CO). The LADOTD crash database has no information on the years of licensure and driver's license status. Due to full-time supervised driving, 15-year-old drivers were involved in only 1.84% of cellphone crashes. According to Louisiana's GDL framework, the minimum age for a learner permit and intermediate driving stage is 15 and 16 years, respectively. Therefore, "Driver age" was classified into two groups (15–16 years and 17 years) to emphasize the teenagers in the learner/intermediate stage of driving. GDL driving restriction hours (passenger restriction- 6:00 pm to 4:59 am and nighttime restriction- 11:00 pm to 4:59 am) was accounted for by the "crash time" interval. The percentages of variable categories with respect to total cellphone crashes are provided in the Appendix section (Table A1).

Association rule mining (ARM)

ARM, a machine learning approach, can recognize the patterns in a dataset without relying on predetermined hypotheses (Hossain et al. 2021). This study utilized the "apriori" algorithm to reveal the chain of factors influencing cellphone-distracted crashes of novice teenagers.

Let $K = \{k_1,\ k_2,\ k_3, \ldots., k_t\}$ be a set of crash database and each crash observation in K consists of a subset of items (e.g., variable attributes) in itemset, $M = \{m_1,\ m_2,\ m_3, \ldots., m_t\}$. A rule can be written as $P \rightarrow Q$ where P is the antecedent (left hand side- LHS), Q is the consequent (right hand side- RHS), $P, Q \subseteq M$, and $P \cap Q = \emptyset$. In an t-itemset rule, multiple items can be as antecedent. The rules are filtered by three critical parameters- support (S), confidence (C), and lift (L). "Support" can be defined by how often that pattern ($P \rightarrow Q$) appears in the entire dataset, while "confidence" is the proportion of how recurring $P \rightarrow Q$ jointly by the frequency of P occurs in the dataset. "Lift" determines how frequently items are part of the same independent crash incidents. The equations of three parameters are listed below:

$$Support\ (P) = \frac{P}{T} \tag{1}$$

$$Support\ (Q) = \frac{Q}{T} \tag{2}$$

$$Support\ (P \rightarrow Q) = \frac{(P \cap Q)}{T} \tag{3}$$

$$Confidence\ (P \rightarrow Q) = \frac{Support\ (P \rightarrow Q)}{Support\ (P)} \tag{4}$$

$$Lift\ (P \rightarrow Q) = \frac{Support\ (P \rightarrow Q)}{Support\ (P)\ \times\ Support\ (Q)} \tag{5}$$

Here, T = crash frequency, P = number of observations with P, Q = number of occurrences with Q, $(P \cap Q)$ = number of crashes with P and Q together. A lift value greater than 1 means a positive correlation between the antecedent and the consequent, whereas a value less than 1 specifies vice versa.

Results

This study performed ARM analysis based on 706 crash observations with 64 variable attributes to reveal the strongly associated co-occurring contributory factors. The rules were generated considering the attributes of crash severity and cellphone usage as consequent. In ARM, it is crucial to define a suitable minimum threshold of support (S) and confidence (C); otherwise, the algorithm could generate abundant rules. This study identified these values through several trials and errors (Hossain et al. 2021). The maximum number of antecedents was restricted to 4 for ease of interpretation.

Rules by crash severity

The minimum support and confidence were set at 1% and 50% to generate rules, with "crash severity: confirmed injury" and "crash severity: possible/no injury" as consequent. The number of association rules was 4,370, with a lift value greater than 1. In ARM, the lift value is more important in understanding how strong an association rule is. For example, rules with a lift value higher than 1 indicate these co-occurring associations are more than expected (Rahman et al. 2021). The top 18 rules ordered from higher to lower lift values are presented in Table 2.

The first 13 rules (M#1-M#13) of Table 2 describe the affiliated categories that contributed to confirmed injury crashes, and the remaining rules explain patterns of possible/no injury collisions. Rule M#1 exhibits that the probability of confirmed injury crashes is 10.46 times if unrestrained novice teenagers use cellphones during late-afternoon hours in clear weather. Louisiana has enacted primary seatbelt laws since 1995; however, the severe consequences of unrestrained driving are still visible among teen drivers (Hossain et al. 2021). Previously, multiple studies reported that young drivers were less likely to wear seatbelts when using cellphones (Rahman et al. 2021; Hossain et al. 2022). From the generated rules, the cumulative effect of unrestrained driving and cellphone usage is also apparent when novice teenagers are female (M#8), at 17 years of age (M#4, M#5), operate passenger cars (M#3, M#9, M#13), travel at weekends (M#11), and drive carelessly (M#12). According to Rule M#7, such a combination of risky driving increases the risk of single-vehicle injury collisions by 7.47 times. This result is consistent with Wu et al. (2022), who investigated the heterogeneous effect of contributing factors on injury severities of cellphone-involved single-vehicle collisions. Intersection on curves is present in the top 3 rules that illustrate possible/no injury crash patterns (N#1-N#3). The explanation of rule N#1 (S: 1.42%, C: 100%, L: 1.08) is: a) 1.42% of cellphone crashes have a possible/no injury in which 17-year-old teenagers drive on curve roadways with an intersection, b) Out of all cellphone crashes in the similar roadways involving 17-year-old drivers, 100% have possible/no injury severity, c) the proportion between possible/no injury cellphone crashes with 17-year-old teenagers traveling on the specified roadways is 1.08 times the same proportion in the complete dataset. Greater speed deviation at intersections could increase the risk of collisions (Charlton 2004), specifically for novice teenagers with less driving experience in complex road environments (Hossain et al. 2021).

Rules for "cellphone usage: Talking/listening"

This study generated rules considering three basic types of cellphone tasks as consequent (Owens et al. 2018) to discover the combination of items associated with specified cellphone distracted behaviors. The minimum support and confidence were 0.7% and 80% to generate rules related to "cellphone usage: talking/listening", "cellphone usage: texting/browsing/dialing", and "cellphone usage: reaching for/answering/locating". The number of generated rules was 44 with a lift value greater than 1.

Table 3 illustrates the 17 rules for "cellphone usage: talking/listening" in the descending order of lift values. Most of the generated rules include "gender: male", "violation: failure to yield", "crash type: left-turn", "age: 17 years", and "movement prior to crash: turning left". Jannusch et al. (2021) reported that cellphone conversation was more prevalent among young male drivers. The combined effect of talking/listening and failure to yield increases the

Table 2. Top 18 rules by crash severity.

ID	LHS	S/C	L	ID	LHS	S/C	L
M#1	crash time: 2-5:59pm, weather: clear, no seatbelt usage: yes	1.13/80.00	10.46	M#10	cellphone usage: unknown, lighting condition: daylight, no seatbelt usage: yes	1.84/56.52	7.39
M#2	crash time: 2-5:59pm, no seatbelt usage: yes	1.13/72.73	9.51	M#11	day of the week: weekend, no seatbelt usage: yes	1.27/56.25	7.35
M#3	vehicle type: passenger car, lighting condition: daylight, no seatbelt usage: yes	1.13/66.67	8.72	M#12	weather: clear, no seatbelt usage: yes, violation: careless operation	1.13/53.33	6.97
M#4	age: 17 y, lighting condition: daylight, weather: clear, no seatbelt usage: yes	1.13/66.67	8.72	M#13	vehicle type: passenger car, no seatbelt usage: yes	1.27/52.94	6.92
M#5	age: 17 y, lighting condition: daylight, no seatbelt usage: yes	1.27/64.29	8.40	N#1	age: 17 y, road geometry: intersection on curve	1.42/100.00	1.08
M#6	lighting condition: daylight, weather: clear, no seatbelt usage: yes	1.70/60.00	7.84	N#2	weather: clear, road geometry: intersection on curve	1.42/100.00	1.08
M#7	crash type: single-vehicle, no seatbelt usage: yes	1.13/57.14	7.47	N#3	no seatbelt usage: no, road geometry: intersection on curve	1.56/100.00	1.08
M#8	gender: female, no seatbelt usage: yes	1.13/57.14	7.47	N#4	cellphone usage: unknown, lighting condition: daylight, violation: no violation	1.13/100.00	1.08
M#9	vehicle type: passenger car, weather: clear, no seatbelt usage: yes	1.13/57.14	7.47	N#5	violation: no violation, movement prior to crash: straight ahead	1.42/100.00	1.08

Note: M#1-M#13: confirmed injury (KAB) as consequent, N#1-N#5: possible/no injury (CO) as consequent, S/C: support and confidence values in percentage.

Table 3. Rules for talking/listening on the cellphone.

ID	LHS	S/C	L	ID	LHS	S/C	L
P#1	gender: male, crash type: left-turn, crash severity: possible/no injury, violation: failure to yield	0.71/100.00	9.54	P#10	gender: male, violation: failure to yield, movement prior to crash: turning left	0.85/85.71	8.18
P#2	gender: male, crash type: left-turn, no seatbelt usage: no, violation: failure to yield	0.71/100.00	9.54	P#11	gender: male, crash type: left-turn, violation: failure to yield	0.71/83.33	7.95
P#3	gender: male, road type: urban-two-way-undivided, violation: failure to yield, movement prior to crash: turning left	0.71/100.00	9.54	P#12	vehicle type: passenger car, lighting condition: daylight, movement prior to crash: turning left	0.71/83.33	7.95
P#4	gender: male, lighting condition: daylight, violation: failure to yield, movement prior to crash: turning left	0.71/100.00	9.54	P#13	gender: male, crash type: left-turn, crash severity: possible/no injury, movement prior to crash: turning left	0.71/83.33	7.95
P#5	gender: male, day of the week: weekday, violation: failure to yield, movement prior to crash: turning left	0.71/100.00	9.54	P#14	driver age: 17 y, violation: failure to yield, road geometry: intersection, movement prior to crash: turning left	0.71/83.33	7.95
P#6	gender: male, weather: clear, violation: failure to yield, movement prior to crash: turning left	0.71/100.00	9.54	P#15	driver age: 17 y, vehicle type: passenger car, violation: failure to yield, movement prior to crash: turning left	0.71/83.33	7.95
P#7	gender: male, crash severity: possible/no injury, violation: failure to yield, movement prior to crash: turning left	0.85/100.00	9.54	P#16	gender: male, crash severity: possible/no injury, road geometry: intersection, movement prior to crash: turning left	0.71/83.33	7.95
P#8	gender: male, no seatbelt usage: no, violation: failure to yield, movement prior to crash: turning left	0.85/100.00	9.54	P#17	gender: male, crash severity: possible/no injury, day of the week: weekday, movement prior to crash: turning left	0.71/83.33	7.95
P#9	age: 17 y, vehicle type: passenger car, day of the week: weekday, movement prior to crash: turning left	0.99/87.50	8.35				

Table 4. Rules for texting/browsing/dialing on the cellphone.

ID	LHS	S/C	L	ID	LHS	S/C	L
Q#1	vehicle type: van/SUV, violation: disregarding traffic control, movement prior to crash: straight ahead	0.71/100.00	4.64	Q#9	day of the week: weekend, lighting condition: dark-lighted, number of passengers: none, movement prior to crash: straight ahead	0.71/83.33	3.87
Q#2	crash type: single-vehicle, day of the week: weekend, violation: others, road geometry: straight segment	0.71/100.00	4.64	Q#10	gender: female, vehicle type: van/SUV, road geometry: straight segment, number of passengers: none	0.71/83.33	3.87
Q#3	crash type: single-vehicle, vehicle type: pickup truck, lighting condition: dark-lighted, movement prior to crash: straight ahead	0.71/100.00	4.64	Q#11	crash time: 6-10:59pm, day of the week: weekend, weather: cloudy, number of passengers: one	0.71/83.33	3.87
Q#4	gender: male, day of the week: weekend, weather: cloudy, number of passengers: one	0.85/85.71	3.98	Q#12	age: 15-16 y, day of the week: weekend, weather: cloudy, number of passengers: one	0.71/83.33	3.87
Q#5	crash type: single-vehicle, vehicle type: van/SUV, road type: rural-two-way-undivided, road geometry: straight segment	0.85/85.71	3.98	Q#13	day of the week: weekend, weather: cloudy, road type: urban-two-way-undivided, number of passengers: one	0.71/83.33	3.87
Q#6	vehicle type: van/SUV, violation: disregarding traffic control	0.71/83.33	3.87	Q#14	gender: female, crash type: single-vehicle, vehicle type: van/SUV, road geometry: straight segment	0.71/83.33	3.87
Q#7	road type: urban-two-way-undivided, violation: others, number of passengers: none	0.71/83.33	3.87	Q#15	crash type: single-vehicle, vehicle type: pickup truck, day of the week: weekend, movement prior to crash: straight ahead	0.71/83.33	3.87
Q#8	crash type: single-vehicle, weather: clear, violation: others, road geometry: straight segment	0.71/83.33	3.87				

likelihood of left-turn collisions for male teenagers (P#1, P#2, and P#11). While entering a highway from a side road, drivers talking on a cellphone provide less emphasis on the incoming traffic and road signs, which could increase the crash likelihood (Beede and Kass 2006). With "cellphone usage: talking/listening", failure to yield during turning left at intersections increases the risk of collision (P#14, P#16). Vehicle approaching and crossing speeds are relatively lower at intersections, and drivers are more likely to engage in cellphone conversions at lower-speed traffic (Tison et al. 2011). This can also be a possible explanation for a strong association between "cellphone usage: talking/listening" and "crash severity: possible/no injury" (P#1, P#7, P#16, P#17). In line with Young et al. (2010), talking/listening involved crashes mostly occur during working days (P#5, P#9, P#17).

Rules for "cellphone usage: Texting/browsing/dialing"

Table 4 lists 15 generated rules with "cellphone usage: texting/browsing/dialing" as consequent. Novice teen drivers operating vans/SUVs are found to be disregarding traffic control when manipulating cellphones (Q#6). The scenario becomes more recurring while going straight (Q#1). Novice drivers spend more time glancing away from the roadways during texting; therefore, they often miss the regular traffic signs and signals (Hosking et al. 2009). The association between weekends and cloudy weather is visible in multiple crash patterns (Q#4, Q#11, Q#13). Yannis et al. (2016) emphasized that cellphone usage in bad weather increased the probability of collisions even if young drivers attempted to reimburse for the increased workloads. Risk-taking maneuvers on weekends during evening hours can be vulnerable for teen drivers (Hossain et al. 2021), which is also reflected when texting/browsing/dialing cellphones (Q#11). Single-vehicle crashes while manipulating cellphones are more likely to occur on weekends (Q#2), while operating pickup trucks (Q#3, Q#15), during dark-lighting conditions (Q#3), on rural two-way-undivided roadways (Q#5), and when female teenagers behind-the-wheel (Q#14). The cumulative effect of “vehicle type: van/SUV” and “road geometry: straight segment” increases the risk of single-vehicle crashes for female teenagers (Q#14), whereas male teen drivers display the crash probability on weekends with passengers in cloudy weather (Q#4). In relation to driver age, crashes are 3.87 times more likely when 15–16-year-old teenagers use cellphones for texting/browsing/dialing on weekends with a single passenger in cloudy weather (Q#12). Previously, teenagers under the GDL program showed risky driving tendencies in similar environments (Hossain et al. 2021). Only straight segments are visible in the generated rules (Q#2, Q#5, Q#8, Q#10, Q#14), which means crashes involving texting/browsing/dialing are less frequent at intersections.

Rules for “cellphone usage: Reaching for/answering/locating”

Table 5 shows 12 association rules generated with “cellphone usage: reaching for/answering/locating”. The cumulative effect of “crash time: 6–10:59pm” and “crash type: sideswipe” is present in the top 5 rules out of 7. Rule T#1 indicates that careless driving of novice teenagers with a single passenger in evening hours is likely to increase the risk of sideswipe collisions by 5.08 times while reaching for/answering/locating the cellphones. Reaching for the cellphone could induce/increase deviation of the steering wheel, which leads to transverse displacement of vehicles, and such movement may significantly contribute to sideswipe collision (Razi-Ardakani et al. 2018). In relation to teenagers aged 15–16, crashes involving reaching for/answering/locating the cellphones on urban-two-way-divided roads in dark-lighted conditions are associated with straight segments (T#10) and multiple passengers (T#8). Novice drivers often face difficulty on urban roadways because of the complexities generated by heavier traffic (Hossain et al. 2022). In such circumstances, cellphone activities in dark conditions could increase crash probability. With “cellphone usage: reaching for/answering/locating”, teenagers in the learner/intermediate stage traveling on urban-two-way-divided roads at dark with streetlights have a risk of rear-end collisions (T#9). Rule T#12 specifies that careless operation of male drivers while reaching for/answering/locating the cellphones in late-afternoon hours at dark-lighted conditions increases the risk of crashes by 4.23 times. In general, the majority of cellphone users are males and use cellphones during late-afternoon hours (Young et al. 2010). None of the rules consists of “number of passengers: none”, implying that novice teens reach for/answer/locate the cellphones in presence of passengers.

Discussion

This study used ARM to investigate crash patterns of novice teen drivers involved in cellphone usage. One of the unique contributions of this study is to introduce different cellphone usage types from the crash reports and identify their association with potential risk factors. This study developed association rules to determine the interrelated crash contributing factors associated with different cellphone tasks and crash severity levels. The results are expected to be beneficial for policymakers and other safety officials to develop strategic planning and implementable countermeasures. Several studies have recommended adding the contextual knowledge

Table 5. Rules for reaching for/answering/locating the cellphone.

ID	LHS	S/C	L	ID	LHS	S/C	L
T#1	crash time: 6-10:59pm, crash type: sideswipe, violation: careless operation, number of passengers: one	0.71/100.00	5.08	T#7	crash time: 6-10:59pm, crash type: sideswipe, day of the week: weekday, weather: clear	0.71/83.33	4.23
T#2	crash time: 6-10:59pm, crash type: sideswipe, day of the week: weekday, violation: careless operation	0.71/100.00	5.08	T#8	age: 15-16 y, lighting condition: dark-lighted, road type: urban-two-way-divided, number of passengers: multiple	0.71/83.33	4.23
T#3	crash type: rear-end, vehicle type: pickup truck, lighting condition: dark-lighted, number of passengers: multiple	0.85/85.71	4.35	T#9	age: 15-16 y, crash type: rear-end, lighting condition: dark-lighted, road type: urban-two-way-divided	0.71/83.33	4.23
T#4	crash time: 6-10:59pm, crash type: sideswipe, violation: careless operation	0.71/83.33	4.23	T#10	age: 15-16 y, lighting condition: dark-lighted, road type: urban-two-way-divided, road geometry: straight segment	0.71/83.33	4.23
T#5	weather: rain, road type: urban-two-way-divided, movement prior to crash: straight ahead	0.71/83.33	4.23	T#11	crash time: 2-5:59pm, lighting condition: dark-lighted, road geometry: straight segment, movement prior to crash: straight ahead	0.71/83.33	4.23
T#6	crash time: 6-10:59pm, crash type: sideswipe, day of the week: weekday, movement prior to crash: straight ahead	0.71/83.33	4.23	T#12	gender: male, crash time: 2-5:59pm, lighting condition: dark-lighted, violation: careless operation	0.71/83.33	4.23

of risk factors into the educational interventions aimed at reducing distracted driving (Klauer et al. 2014; Hossain et al. 2022). Hossain et al. (2021) have suggested to include teen drivers' real-world crash scenarios in the education programs connected with GDL. In this context, the associations identified in this study can be helpful in strengthening the existing driver education programs to mitigate teen driver crashes. Moreover, cellphone crashes and subsequent injuries can be reduced by eliminating or improving one of the attributes involved in the crash patterns.

This research emphasizes the complexity of specifying key risk factors associated with cellphone crashes of novice teenagers. The generated rules provide valuable insights regarding the interdependence between crash contributing factors. The cumulative effect of cellphone distraction and no seatbelt use has been repeatedly visible in confirmed injury crashes, indicating that active enforcement of seatbelt laws can reduce cellphone crashes and related casualties. The results show that cellphone usage with unrestrained driving is frequent between 2 pm and 5:59 pm. High-visibility belt law enforcement programs and efficient roadside inspections in the late-afternoon hours can help to curb such violations. In relation to possible/no injury crashes, cellphone use on curves with an intersection is found to be susceptible even if novice teenagers drive with seatbelts and in clear weather. At intersections, cellphone crashes are more apparent while talking/listening rather than texting/browsing/dialing and reaching for/answering/locating. Therefore, improving the enforcement of existing cellphone laws through increased surveillance at intersections needs to be ensured. From the analysis, novice teenagers talking/listening on cellphones are more likely to be involved in left-turn collisions while failing to yield the right of way. Simulation-based training programs can be arranged for newly licensed teen drivers to validate the defensive driving strategies introduced in the classroom and reinforce safe driving behaviors in complex and hazardous road circumstances. The study outcomes exhibit that teenagers in learner/intermediate stages of driving use cellphone in presence of additional occupants. Education and awareness campaigns can be introduced for both drivers and passengers to stop the behaviors leading to cellphone distracted driving. These campaigns can be incorporated into teen driver education programs and GDL to increase the outreach. The study results also indicate that novice teenagers have a higher crash likelihood on urban-two-way-divided roadways while manipulating cell phones in dark-lighted conditions. As texting during driving is restricted for all groups of drivers, strategic enforcement in hot-spot locations can reduce the related collisions. In this study, the associations among environmental factors and modes of cellphone usage significantly influence the manner of collisions. For example, single-vehicle crashes are associated with cellphone manipulation on weekends in cloudy weather, whereas sideswipe collisions are frequent in evening hours during reaching for/answering/locating the cellphones. In relation to texting/browsing/dialing, novice teenagers operating vans/SUVs are highly associated with traffic control violations. This could call for possible inclusion of maneuvering large vehicles in the behind-the-wheel instructions for driving skill development. Continuous data-driven analysis is also required to implement and evaluate the associated crash countermeasures.

This study has some limitations that can be addressed in the follow-up studies. More than 85% of the operating speed information was miscoded or unknown in the LADOTD crash database, therefore, not included in the study. Further investigation can be conducted to comprehend the vehicle speed deviations due to different cellphone usage types. In this study, the analysis is limited to 4 antecedents, and further research can be done to identify the long patterns from a multitude of factors. Due to several limitations in confirming cellphone usage before collisions, the related information may not be completely accurate in the crash reports. In recent years, the depth and accuracy of crash/near-crash incidents in the Strategic Highway Safety Program's (SHRP2) Naturalistic Driving Study (NDS) data have already been recognized. Apart from traditional crash variables, the dataset includes risky driving measurements such as maximum and mean speed, longitudinal and lateral acceleration rates, brake activations, maximum/minimum/mean distance to a lead vehicle, and so on. Therefore, SHRP2 NDS data can be used to get more insights into the patterns of different cellphone tasks. Several key driver-level factors (e.g., license status) were unknown in the original crash dataset. Understanding the changes in cellphone crash patterns by driver age, driving experience, and driver license status can be a better approach to recommend more specific countermeasures.

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Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Md Mahmud Hossain, data preparation: Md Mahmud Hossain, M. Ashifur Rahman, Xiaoduan Sun; analysis and interpretation of results: Md Mahmud Hossain; draft manuscript preparation: Md Mahmud Hossain, Huaguo Zhou, M. Ashifur Rahman, Subasish Das, Xiaoduan Sun. All authors reviewed the results and approved the final version of the manuscript.

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