

Systematic Review of Military Motor Vehicle Crash–Related Injuries

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Context: Motor vehicle crashes account for nearly one third of U.S. military fatalities annually. The objective of this review is to summarize the published evidence on injuries due specifically to military motor vehicle (MMV) crashes.

Evidence acquisition: A search of 18 electronic databases identified English language publications addressing MMV crash–related injuries between 1970 and 2006 that were available to the general public. Documents limited in distribution to military or government personnel were not evaluated. Relevant articles were categorized by study design.

Evidence synthesis: The search identified only 13 studies related specifically to MMV crashes. Most were case reports or case series ($n=8$); only one could be classified as an intervention study. Nine of the studies were based solely on data from service-specific military safety centers.

Conclusions: Few studies exist on injuries resulting from crashes of military motor vehicles. Epidemiologic studies that assess injury rates, type, severity, and risk factors are needed, followed by studies to evaluate targeted interventions and prevention strategies. Interventions currently underway should be evaluated for effectiveness, and those proven effective in the civilian community, such as graduated driver licensing, should be considered for implementation and evaluation in military populations.

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Introduction

The leading cause of fatalities among U.S. military personnel is motor vehicle crashes, including both privately owned and military motor vehicles. These crashes also rank in the top five causes of injury leading to hospitalization.^{1–3} Although the categories of military motor vehicle (MMV) and privately owned vehicle (POV) crashes are often combined in reporting of safety statistics by military service branches, key differences exist in vehicle engineering and operating environments.

The definition of a military motor vehicle is subtly different between the services, but the term generally includes all wheeled vehicles possessed and in use by the military, either through ownership or lease. Military motor vehicles are further subclassified as either nontactical or tactical vehicles. While nontactical vehicles are standard commercial models, tactical vehicles are either modified commercial models or engineered specifically for military use. Military combat vehicles are tracked rather than wheeled, thus readily distinguished from MMVs. Although operated with controls configured similarly to commercial vehicles, tactical vehicles have different handling characteristics. Also, they may not incorporate safety technology, such as air bags, that is standard in contemporary civilian vehicles. Figure 1 illustrates the current classification of MMVs.

In Operation Iraqi Freedom and Operation Enduring Freedom from 2003 through 2006, MMVs were involved in 85% of the 1024 army motor vehicle crashes that occurred, while military combat vehicles were involved in the remaining 15% (Colonel Peter Mapes, DUSD[R]/RP&A, personal communication, 2007). Operators of MMVs are drawn from a military

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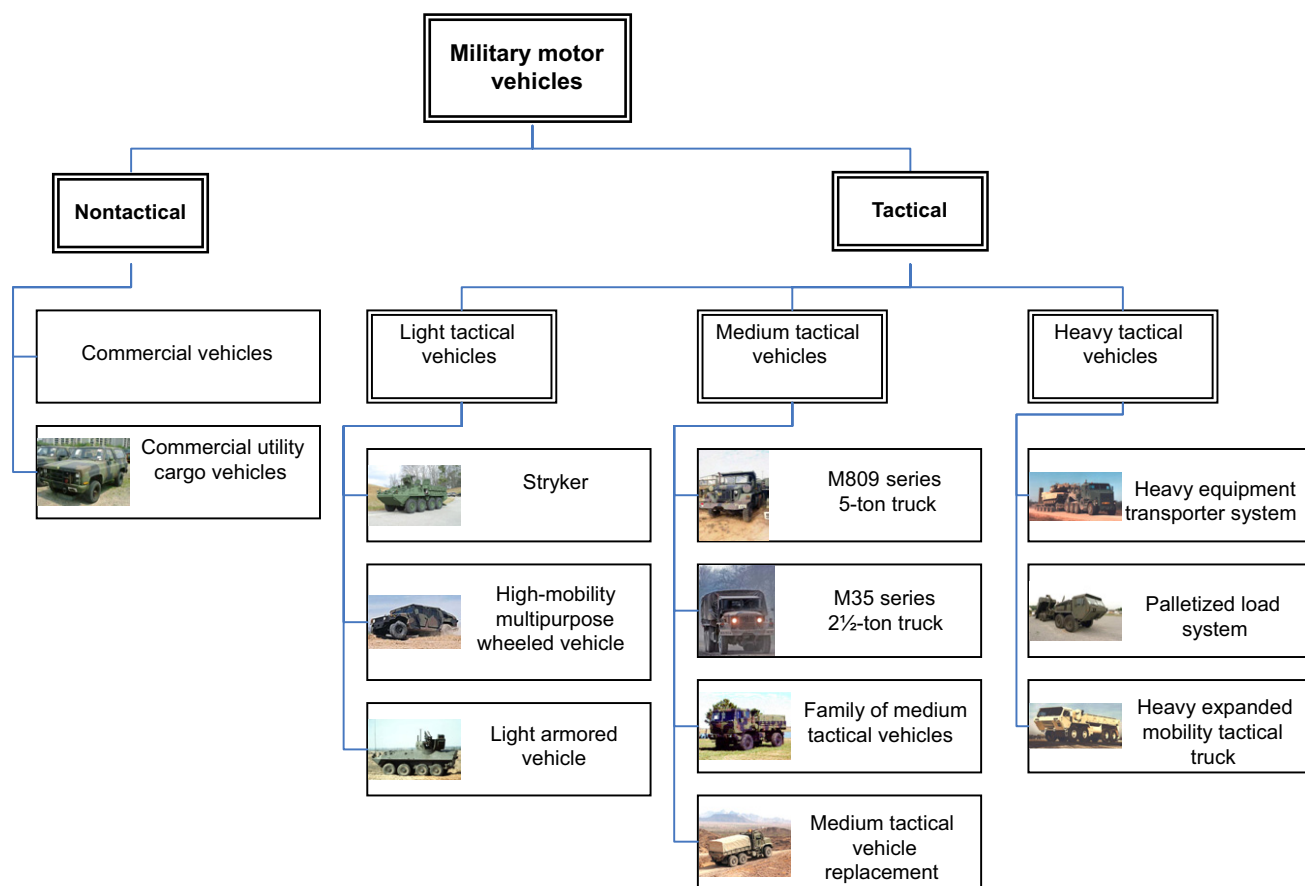


Figure 1. Categories of military motor vehicles

population consisting predominantly of young males. These individuals may have little experience driving privately owned vehicles on U.S. roadways and even less experience driving MMVs in a more risky operational environment. Tactical vehicles operate on- or off-road, in convoys, and in combat settings. Wearing heavy gear, including helmets and body armor, may limit the driver's physical mobility and response to hazardous driving conditions. Military gear also may limit hearing and vision, delaying recognition of imminent hazards.

Given these differences between MMVs and POVs, prevention of MMV crashes may require different or additional interventions compared with those shown to be effective in POV literature. Data on crash rates support the hypothesis that interventions to prevent injuries due to MMV and POV crashes should be evaluated separately. The rate of fatal crashes of privately owned vehicles in the U.S. Army declined from 1980 through 1997,¹ paralleling a decrease in the civilian population that may be attributable to increased seat belt usage and improved vehicle design.⁴ The rate of fatal crashes of MMVs, however, remained lower but

steady through the 1990s before increasing in 2003, coincident with the start of Operation Iraqi Freedom. The rate peaked in 2004 and has trended down from 2005 to the present.^{5–7}

This study sought to specify injuries relating to MMV crashes by consolidating data from the few studies available. Because of differences in crash rate trends between MMVs and POVs, an effort was made to identify effective interventions to prevent injuries related specifically to MMVs. This paper provides the results of a systematic review of the literature that includes descriptive, analytic, and intervention studies of MMV crash-related injuries and demonstrates the need for more evidence on which to base MMV injury prevention efforts.

Evidence Acquisition

A subject matter expert and a university reference librarian assisted in the selection of the search strategy, which used the Medical Subject Headings (MeSH), the text words *vehicle* and *injury*, and derivatives of these terms combined with *military*.

The search included the following databases: Defense Technical Information Center (DTIC) Scientific and Technical Information Network, National Technical Information Service (NTIS) Collection, Proquest, Compendex, Department of Energy Information Bridge, Inspec, Web of Science, Cumulative Index to Nursing & Allied Health Literature® (CINAHL), Cochrane Library, Excerpta Medica Database (EMBASE), PubMed, Canadian Centre for Occupational Safety and Health reference database (OSH), Education Resources Information Center (ERIC), Scopus, Global Health, Allied and Alternative Medicine (AMED), and Evidence-Based Medicine Reviews (EBMR).

Review of all study titles and abstracts identified potentially relevant publications relating to injuries resulting from MMV crashes. Studies meeting inclusion criteria (1) contained data on injuries resulting from MMV crashes or assessed the association between MMV crash injury and potential risk factor(s), a prevention strategy, or an intervention; (2) were written in English; (3) were published between 1970 and 2006; and (4) were publicly available. Studies or reports that evaluated injuries to military personnel resulting exclusively from operation of privately owned motor vehicles or military combat vehicles (i.e., tracked vehicles), or from non-crash related circumstances involving a MMV, were excluded. Relevant articles from secondary references were also retrieved.

Studies meeting inclusion criteria were classified based on study design as engineering studies, case reports or case series, descriptive epidemiologic studies, analytic epidemiologic studies, or intervention studies according to definitions used by the Joint Services Physical Training Injury Prevention Work Group.⁸ Intervention studies specifically examine primary injury outcomes in an intervention group compared to a control group. Analytic epidemiologic studies compare rates or risk of injury between two or more groups. Descriptive epidemiologic studies examine risk or rates of injury in only one group without a comparison group. Case series provide frequencies only but may provide a distribution of risk factors among the injured.

Evidence Synthesis

The search strategy yielded 300 publications, of which only 13 met specified inclusion criteria (Figure 2). Of these 13 publications (Table 1), nine were based on military safety center data, including seven Army Safety Center (renamed the U.S. Army Combat Readiness/Safety Center) annual reports. The classification of these publications by study design and publication year is presented in Table 2. Abstracts of six engineering studies were identified in DTIC's

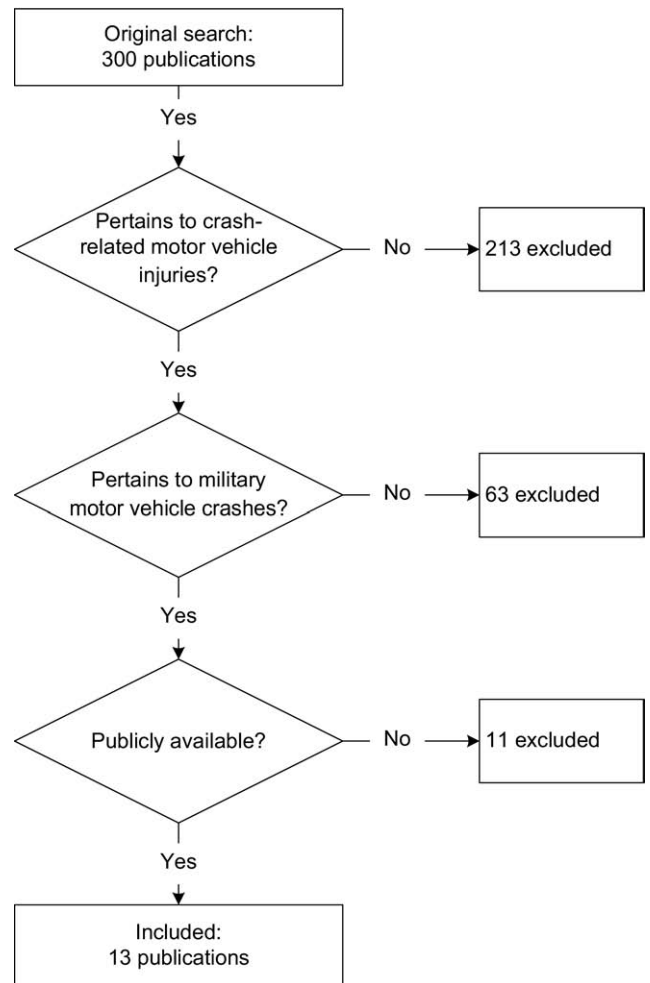


Figure 2. Search results

collection during our search, but these studies are not available to the general public and were, therefore, not considered in this review. Although some publications included both MMVs and POVs, the data were stratified, and only data regarding MMVs are presented here.

Case Series

Annual reports of Army Safety Center data^{9–15} constitute seven of the eight case series identified by the literature search. The specific MMV types included in the reports varied based on the MMVs in service at the time of the report. Four of these reports were from fiscal year (FY) 1986, consisting of an army-wide report and three sub-analyses. Early reports identified MMV materiel failures, such as brake failures or tire blowouts, as a prominent factor contributing to mishaps (28% of mishaps in 1979).^{9,10} Materiel failure then decreased as a reported contributor to MMV crashes, dropping to 9% of mishaps in 1984 and to 7% in 1986 and 1987.^{10,11,15} Rates of mishaps (any severity) were stable over the years reported

Table 1. Summary of published studies meeting inclusion criteria, 1970 to 2006

Title	Authors	Year	Pub type	Study design	Study population	Outcome measures	Comments
Analyses of U.S. Army accident data	Hahn CP, et al.	1971	Report	Case series	Recorded on- and off-duty motor vehicle crashes	Causal factor frequencies	-No comparison group -Recommended studies of risk factors
Analysis of FY79 Army motor vehicle accidents	Ricketson D, Thomas MA	1980	Report	Case series	Reported MMV crashes	Counts	-Count data -No comparison -No context to interpret trends over time
Military and civilian motor vehicle crashes with injuries in Israel: a 5-year comparison	Soudry A, Slater PE, Richter ED	1984	Journal (Travel Med Int)	Case control	Israeli Defense Force vs Israeli civilians	Crash rates (/1,000 vehicles) -urban vs rural -crash type -vehicle type	-Limited generalizability
Management by objective review of Army accident experience FY84	Not listed	1984	Report	Case series	Reported MMV crashes	Counts	-Count data -No comparison -No context to interpret trends over time
Seatbelt use in the Army	Sisk F, Ricketson DS	1985	Report	Ecologic	Drivers on-post	Severity of injury Change in seatbelt usage	-Based on single data source -Poorly described methods -Ecologic fallacy
Army Safety Report FY86 Volumes 1-4 ^a	Not listed	1986	Report	Case series -Armywide+3 subanalyses	Reported MMV crashes	Counts	-Count data -No comparison -No context to interpret trends over time
Army Safety Report FY87	Not listed	1987	Report	Case series	Reported MMV crashes	Counts	-Count data -No comparison -No context to interpret trends over time
New vehicle accident study	Franklin AL, et al.	1991	Report	Case series-vehicle type subanalysis	Reported MMV crashes	Causal factor frequencies	-No comparison group -No denominator -Combines MMVs and combat vehicles
Two studies of military vehicle operator selection and safety	Medsker GJ, et al.	1999	Report	Case series	US Army soldiers	Personal characteristics assoc w/higher crash risk	-MMV/POV combined -Guidelines developed but not validated
Presentation, diagnoses, mechanism of injury, and treatment of soldiers injured in Operation Iraqi Freedom	Cohen SP, et al.	2005	Journal (Anesth Analg)	Case series	OIF casualties referred for pain mgmt (n=162)	Cause of injury leading to referral	-Not specific to MMV -No comparison group

^aEach volume constitutes separate publication identified by our search, resulting in total n=13

(1983 to 1987), but rates of fatalities decreased by about 50% over this same period.

The eighth and final case series evaluated Army Safety Center data pertaining to six specific vehicle

types, including three MMVs and three combat vehicles. Franklin et al.¹⁶ used coded data from 1981 to 1987 to show an upward trend in mishap counts over the study period. They subsequently evaluated mishap

Table 2. Classification of articles by study design and year of publication

Year of publication	Case reports/ series	Descriptive epi studies	Analytic epi studies	Intervention studies	Total
1970–1979	0	1	0	0	1
1980–1989	7	0	1	1	9
1990–1999	1	0	1	0	2
2000–2006	0	1	0	0	1
Total	8	2	2	1	13

reports (DA Form 285-1), providing more detailed information than the coded data, for mishaps involving these six vehicle types in 1985. The authors made site visits to locations where fatal mishaps occurred in 1985 and conducted interviews. The primary problem areas identified for MMVs were human errors (excess speed or following too closely) and impaired driving (alcohol, drugs, or fatigue). The authors' recommendations were specific to each vehicle type, but in general focused on improved driver training to increase awareness of vehicle handling characteristics.

Descriptive Epidemiologic Studies

Hahn et al.¹⁷ attempted to identify human factors, materiel factors, and man/materiel/environment interactions that led to on- and off-duty motor vehicle crashes. The authors analyzed Army Safety Center data that included all motor vehicle crashes occurring in FY 1967. The focus of this study was MMVs, as at the time of the study, MMV crashes were a more frequent source of fatality and injury than POV crashes. The first phase of the study examined the frequency distribution of 28 variables with respect to motor vehicle crashes. The second phase was a regression analysis. This study was limited by the selection bias introduced by examining only crashes. The authors reported that they obtained "no useful results" from their analyses and concluded that further analysis of safety center data to identify risk factors and develop interventions would not be fruitful. Instead, they recommended smaller scale studies designed to answer specific questions. They also noted that exposure estimates based on safety center data were suboptimal. The exposure variable showing the strongest correlation with MMV crashes in their analyses was vehicle miles traveled, accounting for roughly half of the total variance. When coupled with person-hours of driving, these two variables accounted for about 90% of the total variance.

Cohen et al.¹⁸ investigated the etiology of pain among Operation Iraqi Freedom veterans referred to a tertiary pain management clinic. They found that 12.3% of these pain referrals were for injuries sustained in motor vehicle crashes (unspecified vehicle type),

which was the third highest proportion following pain of unknown etiology and post-surgical pain.

Analytic Epidemiologic Studies

Medsker et al.¹⁹ examined driver traits that increase risk of motor vehicle crashes (either POV or MMV). Predictors of elevated crash risk included the following: low perceptual aptitude (measured by the Armed Services Vocational Aptitude Battery), poor adherence to rules and regulations, low tacit knowledge test scores, high rugged individualism interest scale scores, use of drugs/alcohol, off-duty status, late night weekend hours, and major life stressors. The authors recommended selecting MMV drivers with risk profiles based on these predictor variables. Additionally, they recommended counseling at-risk soldiers in order to decrease risky driving behavior. A follow-up study evaluating the effectiveness of driver selection has not been published.

Soudry et al.²⁰ compared rates of motor vehicle crashes involving Israeli Defense Force vehicles to civilian Israeli vehicles from 1978 to 1981. They found that military vehicle crashes were more likely to involve a single vehicle (46% vs 17%). Military crash rates (crashes per 1000 vehicles) were higher for all crash types, but particularly for single-vehicle crashes, with a military to civilian-crash rate ratio of 13.6. Military to civilian-crash rate ratios were also higher for rural roads than for urban roads. Crash rates for two-vehicle and vehicle-pedestrian crashes declined over the study period, but this was not the case for single-vehicle crashes.

Intervention Studies

Only one intervention study was identified by the literature search. In this study, Sisk and Ricketson²¹ examined use of seat belts over a 3-year period during which seat belt usage on military bases became mandatory. The study relied on Army Safety Center data. Violators of the seat belt regulation could be referred to state traffic court. The authors stated that seat belt usage increased over the

3-year period studied but provided limited data to support this statement. Because no systematic collection of data occurred at the local level, the authors relied on anecdotal evidence. For example, they presented data from a single unidentified installation, noting that baseline seat belt usage of 10% while driving on base increased to 29% following nine days of combined media and law enforcement programs. No rates were calculated, but a lower average cost per injury for belted occupants versus unbelted occupants of MMVs was noted over the 3-year period studied (\$3461.96 versus \$7388.03, respectively).

Discussion

Given the large contribution of motor vehicle crashes to military fatalities, this review revealed a surprising paucity of published literature regarding MMV crashes. Although the search did not cover unpublished and non-English language articles, key articles were identified by consulting a reference librarian and a subject matter expert to develop an effective search strategy. Most of the articles identified by this search were descriptive in nature and consisted of counts, not rates, of MMV crashes. Few of the publications included key data elements such as demographics, nature and severity of injuries, injury rates, and data on risk factors. Only one intervention study was identified, but findings were not supported by the data.

A 2007 study by Hammett et al.²² was published after the end of the study period but provides an additional descriptive study. The authors used multiple data sources to examine drowning fatalities due to motor vehicle crashes in Operation Iraqi Freedom and Operation Enduring Freedom. They found that 52 of 71 drowning deaths during the study period were associated with motor vehicle crashes, and 63% of these crashes involved MMVs. Although seat belts were not worn by 95% of the drowning fatalities, only 17% had injuries severe enough to potentially have precluded escape from the vehicle. Based on their analysis, the authors recommended development of training and equipment to expedite rescue of or vehicle egress by occupants.

The relative lack of studies related to MMV crashes is in contrast with a much larger number of published epidemiologic studies focusing on injuries to military personnel involving POVs. Nonetheless, safety center reports and unpublished hospitalization data, as well as ground mishap data from the theater of operations in Iraq and Afghanistan (Colonel Peter Mapes, DUSD[R]/RP&A, personal communication, 2007) clearly indicate that MMV crashes are a problem. These data represent a starting point in the public health process, which begins

with problem description and risk-factor identification, followed by development, implementation, and evaluation of interventions aimed at prevention.

In order to assess the magnitude of the problem, there must be an understanding of the degree to which safety centers capture data on MMV crashes. In addition, the data captured do not include all of the elements needed for epidemiologic analysis. For example, although total vehicle mileage traveled and total military man-hours may be available for use as denominators in the calculation of rates, exposure to MMVs may vary greatly by service branch, military occupational specialty, and unit. Other shortcomings include lack of completeness, detail or standardized collection of data regarding type, location, and severity of injury.

The publications reviewed relied almost solely on safety center data. Further studies using data from multiple sources, including the safety centers, medical databases, police investigative reports, insurance claims data, mortality registries, and administrative data on disability or military separation, will best inform preventive intervention efforts. Epidemiologic studies focused particularly on identifying modifiable risk factors for injuries due to MMV crashes are critically important. Once potential interventions are identified, implementation should be coupled with the collection of both baseline and follow-up data in order to measure and document effectiveness. This information could also be used to better target prevention efforts.

Given that there is some overlap between operation of MMVs and operation of POVs, evaluation of interventions that have proven effective in POVs is reasonable to consider, but these efforts should be prioritized based on presumed applicability to MMVs. Some interventions that have proven effective in the civilian population will not translate to MMVs. For instance, because MMVs are operated when individuals are on-duty, alcohol use is less likely to be an important risk factor for MMV crashes, particularly in tactical vehicles. Since MMV crashes are thoroughly investigated from a legal standpoint, it is reasonable to expect that involvement of alcohol would be reported in safety center data. Review of unpublished data from Operation Iraqi Freedom and Operation Enduring Freedom (Colonel Peter Mapes, DUSD[R]/RP&A, personal communication, 2007) showed that alcohol was present in only 9 of 4536 personnel involved in MMV crashes. Therefore, interventions targeted at alcohol are unlikely to have a large impact on MMV crash rates in theaters of combat operations.

Tactical and nontactical vehicles also need to be considered separately when prioritizing these interventions for evaluation. For instance, interventions targeted at seat belt use in POVs would likely translate well to nontactical

MMVs. However, seat belt use in tactical MMVs presents different challenges and concerns. As reported by Hammett et al., 95% of drowning fatalities in tactical MMVs in the combat theater were not wearing a seat belt.²² Anecdotally, concerns about slow egress in combat situations limit use of seat belts in tactical MMVs. Thus, interventions successful at increasing seat belt usage in POVs might be less likely to increase seat belt usage in tactical MMVs. Studies identifying specific modifiable risk factors and potential engineering solutions for tactical MMVs are critically important.

Changes in safety engineering of tactical MMVs represent a long-term effort, but the importance of vehicle design dictates that every effort should be made to identify specific vehicle characteristics that contribute to MMV crashes. As crash-avoidance safety technologies evolve in the civilian automobile industry, experienced military drivers will be accustomed to them and change their driving behaviors. Behavioral adaptation to crash-avoidance technologies such as anti-lock brakes has been demonstrated.²³ For example, in one study, taxi drivers accustomed to anti-lock brakes were shown to follow more closely than drivers unaccustomed to this technology. Perhaps for this reason, anti-lock brakes have failed to show any association with decreased risk of driver injury.²⁴ These observations suggest that behavioral adaptation of military drivers to these technologies in civilian vehicles could lead to increased risk if crash-avoidance technology in MMVs lags behind the civilian automobile industry.

Safety technology gaps may be reduced by implementing those technologies that have been developed by the automobile industry during the design stage of tactical vehicle production, rather than as a retrofit, as directed by current regulations.²⁵ Due to the length of the acquisition process, the status of safety technology should be periodically revisited.

When tactical MMV risk factors related to differences in handling characteristics are identified, they could potentially be mitigated by using simulator technology to train drivers. This intervention may be more timely and cost effective than an engineering modification for an entire fleet of vehicles. While we recognize that some information on engineering of tactical military vehicles is classified or not for public release due to security concerns, a separate review of these studies may be worthwhile for the military to pursue internally.

Administrative or policy measures to reduce injuries have the potential for immediate impact and are also low in monetary cost. Driver-selection programs are used by the military but have not been evaluated for effectiveness. Drivers of MMVs currently are drawn from the general military population, and a screening process includes reviewing prior traffic violations and some behavioral

traits prior to licensing.²⁶ However, driver selection has not proven effective in the civilian population.²⁷ Alternatively, graduated driver licensing has consistently been shown to be effective among young civilian drivers.^{27–29} This strategy would translate well to the military environment, where new MMV drivers could be required to have a period of driving only under supervision and not during risky conditions, such as at night, in inclement weather, or in combat settings, until this supervisory period has ended.

Conclusion

Essentially all information on MMV crashes is based on service safety center data. These data identify that a problem exists, but there is little detail about the magnitude of the problem or modifiable risk factors. Basic epidemiologic studies are urgently needed to gain a better understanding of this problem and guide development of preventive interventions.

Simultaneously, interventions effective for POVs in the civilian population should be evaluated for effectiveness in MMVs. Tactical and nontactical MMVs should be considered separately when prioritizing interventions for evaluation. Safety engineering features clearly should be incorporated in tactical vehicle design when found to be effective. Administrative interventions may be implemented more rapidly in the military compared with civilian settings and are relatively low cost. In particular, graduated driver licensing has been shown to be effective in young adults in the civilian population, and we recommend that a form of this licensing for MMVs be developed, implemented, and evaluated for effectiveness in preventing MMV crashes and reducing MMV crash-related injuries in military populations.

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