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Head Injury Risk in U.S. Army Rotary-Wing Mishaps: Changes since 1980 (Reprint)

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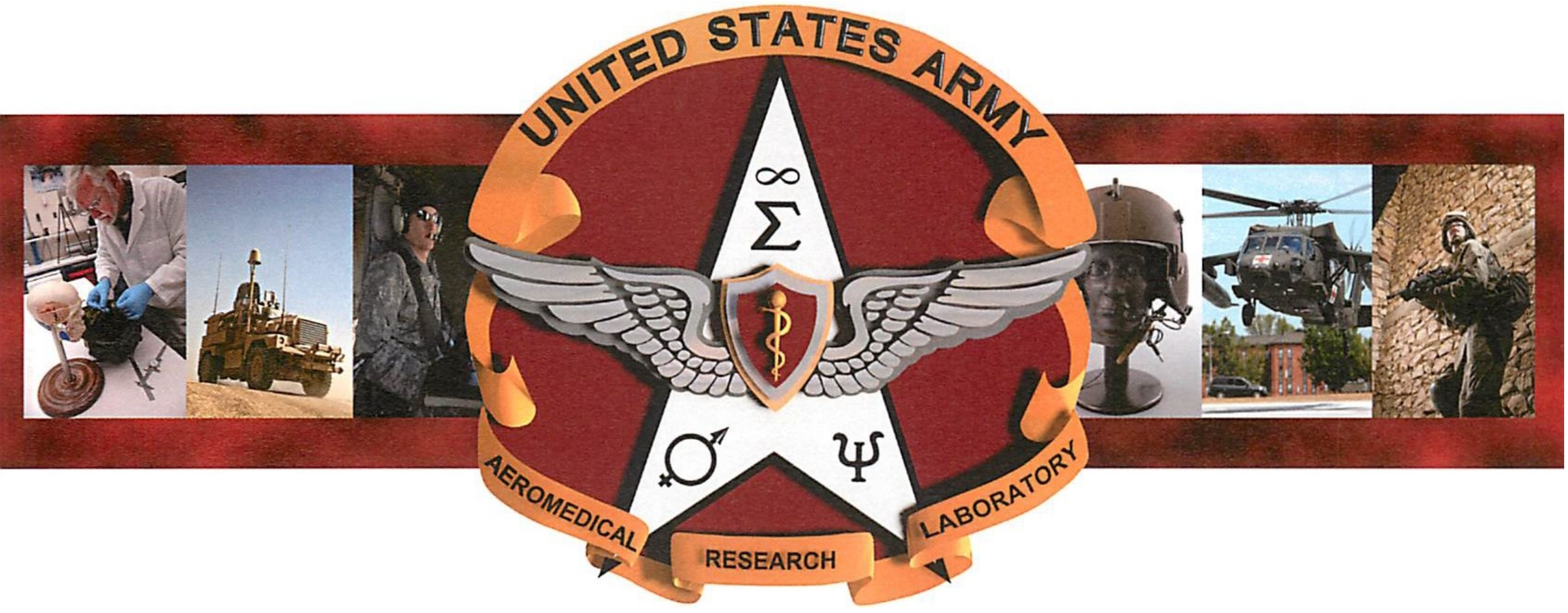

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14. ABSTRACT

Over the past several decades, data have been collected on U.S. Army aircraft mishaps defining the environment within an aircraft during a mishap, injuries suffered by the occupants, and the cause (or causes) of the mishap, if known. An analysis of these data indicates 60 percent of the occupants are injured, one-third fatally, if the mishap concludes with the aircraft impacting the ground. More significantly, despite improvements in helicopter design, restraint systems, and personal protective equipment, 68 percent of all fatalities had at least one fatal injury to the head. After adjusting for differences in mishaps, including the aircraft series, and the occupant's station within the aircraft, the authors concluded that an occupant's injury risk in a helicopter mishap had decreased significantly between 1980-84 and 1990-94. One factor in this was a decline in the risk of head injury, which declined by 50 percent. Injury risks to the face and brain, critical anatomical regions of the head, also showed a significant decline. Risks of injury to the neck, torso, and upper extremities were not significantly different between the two time intervals. (Continued)

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Although the authors could not identify causative factors with clear implications for preventive strategies, the proportion of new, crashworthy helicopters in the U.S. Army fleet have risen steadily since 1980, and a new flyer's helmet with improved impact protection, the SPH-4B, was fielded by the U.S. Army in the 1990s.

Head Injury Risk in US Army Rotary-wing Mishaps: Changes since 1980.

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1. SUMMARY

Over the past several decades, data have been collected on U.S. Army aircraft mishaps defining the environment within an aircraft during a mishap, injuries suffered by the occupants, and the cause (or causes) of the mishap, if known. An analysis of these data indicates 60% of the occupants are injured, one-third fatally, if the mishap concludes with the aircraft impacting the ground. More significantly, despite improvements in helicopter design, restraint systems, and personal protective equipment, 68% of all fatalities had at least one fatal injury to the head. After adjusting for differences in mishaps, including the aircraft series, and the occupant's station within the aircraft, the authors concluded that an occupant's injury risk in a helicopter mishap had decreased significantly between 1980-84 and 1990-94. One factor in this was a decline in the risk of head injury, which declined by 50%. Injury risks to the face and brain, critical anatomical regions of the head, also showed a significant decline. Risks of injury to the neck, torso, and upper extremities were not significantly different between the two time intervals. Although the authors could not identify causative factors with clear implications for preventive strategies, the proportion of new, crashworthy helicopters in the U.S. Army fleet have risen steadily since 1980 and a new flyer's helmet with improved impact protection, the SPH-4B, was fielded by the U.S. Army in the 1990's.

2. INTRODUCTION

One of the first investigations of occupant injury in U.S. Army rotary-wing aircraft mishaps was conducted by Shanahan and Shanahan [1] in 1989. The authors presented statistics on crash velocity, type of injury, and injury characteristics in rotary-wing mishaps that occurred between 1980 to 1985. Of the 1,060 occupants in these mishaps, 136 were killed and another 475 suffered significant, but nonfatal injuries. More significant to this investigation, Shanahan and Shanahan differentiated between those injuries induced by acceleration and those injuries resulting from contact. According to Shanahan, acceleration-induced injuries result from the occupant's inertial response to acceleration force. Contact injuries, on the other hand, result from the occupant striking or being struck during the crash sequence. They reported a high prevalence of contact injuries to the head, prompting renewed developmental efforts in this area.

Concerns about contact injury prompted Raddin [2] to conduct a similar study using U.S. Air Force mishaps. Among the 620 occupants in Raddin's study, 126 were killed, while 100 more sustained injuries which resulted in lost days away from work or restricted duty. As in Shanahan and Shanahan's research, head injuries pre- dominate among the fatalities. Among survivors, spinal injuries are the predominate injury. It is likely that the high incidences of spinal injuries in USAF mishaps reflect acceleration-induced injuries during ejection and the parachute landing that follows.

This study expands on Shanahan and Shanahan's foundation, the authors examining historical data from U.S. Army rotary-wing aircraft mishaps that occurred during the 15-year period between 1 January 1980 and 31 December 1994. The toll during this period was 441 fatalities and 1,112 days lost/restricted duty injuries, ranking rotary-wing aircraft mishaps as one of the leading causes of mortality and morbidity among U.S. Army personnel. If Shanahan and Shanahan's assessment of injury causation are correct, as many as one-third of these fatalities and days lost/ restricted duty injuries resulted from contact injury to the head, many of which were preventable.

This study investigates injury to determine if the prevalence of contact injury to the head has changed since 1985. Since 1985, the U.S. Army has fielded thousands of SPH-4Bs, a new version of its SPH-4 flyer's helmet, and has upgraded the impact protection of thousands of older SPH-4s. Additionally, old aircraft have been replaced by new aircraft with improved crashworthiness, From an academic viewpoint, this study compares the distribution of injury for three 5-year intervals: 1980-84, 1985-89, and 1990-94. It provides quality benchmark data (that can be used for numerical analysis) on the prevalence of traumatic injury in U.S. Army rotary-wing mishaps.

3. MATERIALS AND METHODS

Selection of mishaps

The U.S. Army Safety Management Information System (ASMIS) was queried to identify all rotary-wing mishaps involving AH-1 (Cobra), AH-64 (Apache), CH-47 (Chinook), OH-58 (Kiowa) OH-6 (Cayuse), UH-1 (Iroquois), and UH-60 (Black Hawk) series helicopters that occurred between 1 January 1980 and 31 December 1994. Although other aircraft series were operated by the U.S. Army during this period, these mishaps were not included because of differences in operational use of the aircraft and the small percentage of the overall fleet represented.

The Army's aircraft mishap classification schema, defined in DA PAM 385-40 [3], is based on cost of the property damage or the level of injury sustained by the occupants, whichever is greater. Criteria are revised periodically, the last revision being in November 1994. Table 1 provides an overview of the cost and injury criteria contained in this revision of DA PAM 385-40. Because of its focus, the study was restricted to Class A, B, or C, mishaps where injury was likely to have occurred.

Mishaps also are classified by *survivability*. Survivability is defined in the Aircraft Crash Survival Design Guide [4]. A mishap is said to have been survivable only if the impact forces involved are within limits of human tolerance and the occupied space within the helicopter was sufficiently maintained throughout the crash sequence to permit each occupant's survival. If none of the occupied stations within a helicopter meet these criteria, the mishap is said to have been nonsurvivable. If some, but not all, of the occupied stations within the helicopter met these criteria, the mishap was said to be partially survivable. This determination of survivability is independent of actual survival, therefore, a mishap could have no survivors but be classified survivable. Likewise, a mishap could result in no injuries but be classified as nonsurvivable.

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The initial query of the ASMIS database identified 1,296 aircraft (AH-1, AH-64, CH-47, OH-58, OH-6, UH-1, and UH-60) in 1,268 rotary-wing mishaps (Class A, B, or C) which occurred between 1 January 1980 and 31 December 1994. Narrative summaries and kinematic data (impact velocities, impact angles, and terrain characteristics) were then reviewed to identify those mishaps in which the helicopter did not impact the earth, i.e., wire or blade-strikes where the helicopter subsequently landed safely, aircraft fires that occurred during refueling, mishaps where the occupant fell from the helicopter during flight but the helicopter was not damaged, mishaps where individuals were struck by rotor blades while the helicopter was on the ground, mishaps where the helicopter was damaged by wind while taxiing, and mishaps where damage was limited to a load suspended from the helicopter, were excluded. After exclusions, the final data set consisted of 672 mishaps involving 683 helicopters. (The number of aircraft exceeds the number of mishaps because of mishaps with more than one aircraft.) For clarity, these are said to be *ground-impact mishaps*.

Table 2 provides a summary of the 672 ground-impact mishaps in the final data set. Station and degree of injury (DEGINJ) also are provided for the 2,337 occupants in these helicopters. Two occupants were coded as "missing." As several years have passed since their mishap, these occupants were presumed dead.

Creation of injury profiles

Since Shanahan and Shanahan first described the high frequency of head injury in U.S. Army helicopter mishaps, ASMIS has provided important insights into the determinants of traumatic injury. Developed to provide researchers with a simple method of describing environmental, social, and mechanical aspects of a mishap, ASMIS currently lists up to seven injuries to each occupant in a mishap. If an occupant receives more than seven, injuries are ranked by severity and the seven most serious are recorded in the database. A U.S. Army flight surgeon, participating in the accident investigation, determines the ranking.

The goal of this study was to describe any changes in occupant injury patterns since 1980. More specifically, we would like to be able to determine the distribution of injuries to each occupant and describe any changes to this distribution over time. The distribution of injuries was determined by an aggregate of four ASMIS fields: BREG (body region), INJTYPRS (injury type), CAUDEA (cause of death), and DEGINJ (degree of injury).

ASMIS conceptualizes the human body as composed of 5 major anatomical regions: Head, neck, torso (chest, abdomen, and pelvis), upper extremities (arms), and lower extremities (legs). These regions are identified by the first digit in the field, **BREG**. The next two digits in BREG identify specific anatomic structures within each region. Injuries involving more than one anatomical region are grouped into a single, catchall classification "General body injury." An example of such injuries would be a thermal burn, extending over 75% of the individual's body. As this code does not provide specific information on an injury and is virtually useless for comparative purposes, a concerted effort was made to minimize this code. This was done using a combination of the flight surgeon's notes in the case file, cause of death in ASMIS, and mishaps narratives. For example, the cause of death was 'decapitation', the injury was coded as either an injury to the head or neck depending on whether the cervical spine was transected. Likewise, if the injury was a 'concussion,' the injury was coded to reflect injury to the brain. Coding 'loss of consciousness' proved to be more difficult. The consensus among the investigators was that loss of consciousness could reflect the occupant's 'blacking-out' due to pooling of blood in the extremities or movement of the brain within the skull in response to contact partially mediated by the helmet. The decision criteria used was that if the narrative cited confusion or disorientation confirmed by another observer, loss of consciousness was an indicator of brain trauma. Otherwise, it was not. This coding is consistent with the instructions for categorizing loss of consciousness by the Association for the Advancement of Automotive Medicine in the Abbreviated Injury Scale 1990 Revision (AIS 90) [5].

When appropriate, major anatomical regions of the occupant's body were divided into smaller, subregion. This was accomplished by using the second and third digits of the ASMIS field, BREG. The head, because of its clinical importance, was divided into three subregions: Face, brain, and skull. Similarly, the cervical spine was broken out of the neck. Because of its size and complexity, the torso was divided into 4 subregions: Major organ systems, thoracic spine (T1-T12 vertebrae and their related IVD), lumbar spine (L1-L5 vertebrae and their related IVD), and the spinal cord. Injuries within a region not identified as within to a specific subregion were simply classified as 'any other structure.'

During the next step, injuries were summed for each body region (and subregions). A profile of injuries, based on the number of regions with traumatic injuries, was created. The profile of body regions with injuries was called an occupant's *injury profile*. An occupant was considered injured if they suffered one or more injuries to any body region. Likewise, the occupant was considered killed if any injury was fatal, *DEGINJ* was coded as "A" (Killed) or "H" (Missing, presumed dead), or a 'cause of death' was present.

The final step in analysis of ASMIS injury data was to estimate an occupant's injury severity score (ISS). In 1984, ASMIS was modified to allow coding of severity for individual injuries. A field, INJSEV, was added which described injury severity using a six-point scale from first aid (1) to fatal (6). This coding schema is compatible, to the extent possible, with the scoring schema used in AIS 90 to describe injury severity. Using the method described by Baker et al. [6], an ISS was computed for each occupant in the mishap. Computationally, ISS is the sums of squares of the highest score for the three most seriously injured body regions. Since the body regions used to calculate an ISS do not coincide with ASMIS body regions (nor with AIS 90 body regions), this necessitated further coding. ISS divide the body into six anatomical regions: Head/neck, face, chest, abdomen, extremities, and external. We elected not to code external injuries (lacerations, abrasions, contusions, and burns) separately but to retain these injuries within the body region affected. In accordance with the Injury Scaling Committee's instructing in AIS 90, loss of consciousness was given an injury severity score of '2' if it was witnessed, resulted in confusion or disorientation, and was less than 1 hour in duration. Finally, any individual with one or more fatal injuries was automatically assigned an ISS of 75.

Classification of mishaps

Mishaps were divided into two groups based on the survivability of the aircraft: Potentially-survivable and nonsurvivable. A potentially-survivable mishap is one where any occupied station was potentially survivable, i.e., a survivable or partially-survivable mishap. Nonsurvivable mishaps are those where no occupied stations were said to be survivable; that is, all occupied stations were classified as nonsurvivable. In general, non-survivable mishaps are catastrophic events with multiple fatal injury producing mechanisms. Less that 15% of occupants in nonsurvivable mishaps survived the mishap, less than 1% were uninjured in the mishap.

Mishaps also were categorized according to their date of occurrence. The 15-year study interval was divided into three 5-year

1984), Period II (1 January 1985 through 31 December 1989), and Period III (1 January 1900 through 31 December 1994). The 5-year intervals were chosen because Period I roughly replicate the interval described in Shanahan and Shanahan's study [1].

Classification of occupant station

Within an aircraft, an occupant's location within the helicopter is said to be their 'station.' To simplify analyzes, all occupants were assigned to one of three stations: Pilot/copilot (PC), crew chief/engineer/aerial gunner (CEG), and passengers (PAC). (In a tandem-seat attack helicopter the gunner station is the copilot station, therefore the gunner station in these aircraft was coded as PC.) The PC station is well documented and the protective equipment worn by occupants of this station are generally standardized, therefore, it was decided to classify all occupants into two stations: PC and all others. This change affected only the occupants of the crew chief/engineer/ aerial gunner station who were combined with passengers.

Statistical analyses

Analyses were conducted in three stages. First, traumatic injury to each body region was examined by comparing the frequency distribution of injury counts. Next, we formally tested the null hypothesis that injury risks have declined in comparing injuries in Period I with injuries in Period III. Clinically, the body is divided into several anatomical regions. Therefore, in comparing injury rates we divided the body into five anatomical regions. This provided an estimate of the effect of time on the risk of acceleration and contact injury. We previously reported that new, high performance helicopters exhibit higher injury rates possibly related to a distinct tendency for these helicopters to impact with high vertical velocity. Therefore, relative risks were estimated using multivariate logistic regression to adjust for survivability, occupant station, and helicopter type. For all relative risk estimates, we provide 95 percent test-based confidence intervals (CI_{95}) when appropriate. Student's T Tests (or multivariate Analysis of Variance (ANOVA) when appropriate) were used to compare ISS values. As the calculation of ISS values was possible only after 1983, these comparisons were limited to mishaps which occurred after January 1, 1985 (Periods II and III). P-values, based on 95% confidence intervals are provided for these estimates.

4. RESULTS

Over the 15-years of the study, 1,226 aircraft of the seven helicopter series previously discussed were involved in Class A, B, or C mishaps. Six hundred and eight-three of these mishaps involved the aircraft actually striking the ground (55.7%), that is, a ground-impact mishap. Acquisition and retirement of aircraft have changed the Army helicopter fleet significantly over the past decade. A breakdown of the distribution of the 683 'study' aircraft is provided for each of the three time intervals in the study as Table 3. As the AH-64 Apache entered the U.S. Army fleet in 1984; no Apaches crashed during the first five years of the study.

Of the 2,337 occupants in the 683 aircraft, 1,395 were reported as being injured (59.7%), 401 fatally (17.2%). Table 4 provides a survey of injuries and fatalities by helicopter series.

In Table 4, the first column reflects the helicopter series, the second the number of occupants in mishaps involving this series, the third the number of occupants injured, and the last the number of occupants killed. For example, there were 188 individuals in 94 AH-1 aircraft. Of these 165 suffered at least one injury (87.8%) and 33 (17.6%) were killed. By comparison, 48 of the 62 (77.4%) individuals in AH-64 mishaps were injured, 9 (14.5%) fatally.

A summary of traumatic injury by body region is provided as Table 5. The first column defines the body region affected (or subregion, if appropriate). The next represent the number of injured occupants for each region or sub-region. The third column displays a percentage. For regions, this value represents the percentage of injured occupants. For subregions, the percentage reflects the percentage of occupants with injuries to a specific subregion within that region. The fourth represents the ranking of the region within major body regions or subregions within a major region. Columns 5 through 7 describe injury profiles for all occupants for each of the three 5-year periods. The risk of traumatic injury rose during the second 5-year period, before falling during the third. If this trend continues, statistical significance will eventually be reached.

Thirteen hundred and eighty-five of the 2,337 occupants in the study aircraft were injured. Of these, 638 (27.3%) suffered at least one injury to the head. Head injuries ranked second in terms of most frequently body region injured behind the torso. Analysis of subregions, reveals that 264 (41.4%) of individuals with head injuries suffered at least one injury to the face. Of clinical importance is that while 254 injured occupants (39.8%) suffered brain injuries (mostly concussions), only 142 (22.3%) had fractures of the bony components of the head. Between Period I and Period II, the prevalence of head injury rose by 35% (33.6/24.8=1.354), including a 70.4%(15.65/9.18=1.704) increase in brain injury. Fortunately, during Period III the prevalence of brain injury declined to 7.2% of the overall study population, 30.9% of occupants with head injury.

The unadjusted relative risk estimates for all occupants, grouped by body region, are shown in Table 6. These estimates were derived by comparing the injury risk in Period III with the injury risk in Period I (defined as baseline). None of these estimates were statistically significant, although many showed marked improvement Readers who have not had experience with the relative risk and its estimation are referred to Hosmer and Lemeshow [8].

Subgroup analysis of injury trends revealed a pattern of very high injury prevalence among occupants in nonsurvivable mishaps. In nonsurvivable mishaps, 86.3% (328 of 380) of the occupants were killed. Over the 15-years of the study, only three occupants in nonsurvivable crashes were uninjured. Moreover, injury trends suggest possible reporting bias for head injury in nonsurvivable crashes. That is, a flight surgeon was more likely to include head injuries among the seven injuries in ASMIS than injuries to other body regions. To assess the impact of a reporting bias, injury profiles in occupants in potentially-survivable mishaps were developed. Other than dropping the occupants in nonsurvivable crashes, Table 7 duplicates Table 5.

Table 7 is important because it suggests a declining trend for head injury. The prevalence of head-injured occupants in potentially survivable helicopter mishaps fell by 26% between Period I and Period III. Most of this decline seems to be related to a reduction in the number of occupants with brain injury. Prior to Period III, 31% of all head injured occupants suffered at least one brain injury; during Period III this number fell to 19%. The decline in the proportion of head-injured occupants with brain injury resulted in a rise in the proportion with facial injury (s). Overall, however, the proportion of crash occupants with facial injury declined slightly from 10.3% in Period I to 9.4% in Period III. The proportion of crash occupants who suffered torso injuries remained fairly constant over the 15-years of the study at 27.8-29.5%. However, the proportion of torso injury involving the major organ systems dropped significantly from 32.6% to 16.0%. Unadjusted relative risk estimates were calculated from these data. Presented as Table 8, the relative risk estimates suggest a linear trend of declining risk. Within specific anatomical regions, the risk of head injury declined significantly, driven by a significant decline in the risk of brain injury. There was no decline in the risk of neck, torso, or upper extremity injury. However, within the torso, the risk of major organ system injury declined. As expected, this decline was matched by an increase in the risk of other injuries to the torso, predominately minor strains and contusions to the back. Perhaps more significant, there was a decline in the risk of lower extremity injuries. This is important because it tends to refute the hypothesis of a reporting bias in head injury previously discussed.

A crewmember's station has been used in accident investigations for years; but it was not until recently that differences in injury risk between crew stations was fully appreciated. In this study, crew stations were either classified as pilot/copilot (PC) or other. The distribution of occupants stratified by crew station and ASMIS survivability are provided as Table 9. These data reveal that 59% of the occupants in potentially survivable crashes were in the PC station versus 51% in nonsurvivable crashes.

Table 10 presents injury patterns for occupants in the pilot/copilot station, limited to potentially survivable mishap. The data in Table 10 are presented in the same format as Tables 5 and 7 with the first columns representing the overall study and the last columns representing the 3 5-year intervals.

Fifty-two percent of PCs in potentially survivable crashes were injured, 3.8% killed, over the 15 years of the study. Ranking body regions from most frequently injured to least frequently injured, the torso was most the frequently injured body region and the neck the least. The head region ranked third behind the lower extremities, with 20.5% of all PCs suffering at least one head injury.

Comparing injury profiles across 5-year intervals, the proportion of injured PCs fell from 55.6% in Period I to 47.3% in Period III. More significantly, mortality fell from 5.7% to 2.1% over the same period. Many of the lives saved may be attributable to a reduction in head injury risk also observed. The risk of head injury fell from 20.6 in Period I to 15.4% in Period II, a decline of by 25.3%. More significantly, the risk of brain injury fell from 7.3% (36 of 491) to 2.7% (8 of 292). Likewise, the risk of skull fractures fell from 5.1% in Period I to 3.76% in Period III. As a proportion of head injuries, the risk of facial injury and skull fracture remain relative constant throughout the study.

The risk of torso injury remained relatively flat, beginning at 28.3% and ending at 26.3%. Within the region, the prevalence of vertebral fractures and spinal injury was essentially unchanged, although the risk of injury to the major organ systems declined significantly from 30.2% of torso injuries to only 13.2% of torso injuries. As a percentage of the population, crew members with major organ system injury declined from 8.6% to 3.4% in a decade.

In Table 11, the unadjusted relative risks for the PC in potentially survivable injuries are presented. As before, the overall risk of injury decreased. The decline in head injury was only borderline in significance, with a reduction in brain injury possibly the primary factor in this change. As before, there was no decline in the risk of injury to the neck, torso, and upper extremities. Although injuries to the major organ system(s) of the chest and abdomen declined significantly, possibly related to changes in helicopter design, the risk of leg injury also declined.

Again, comparing ISS values for Period II with ISS values for Period III yielded significant declines. The mean ISS value for PCs in Period II was 10.516 declining to 7.39 in Period III (Student's T=2.45, p=0.0125). Restricting the comparison to injured PCs, the mean ISS in Period II was 20.47 versus 15.59 in Period III (Student's T=2.31, p=0.02).

A potential confounder which could mask injury trends in U.S. Army helicopter mishaps is the phenomenon of replacement, wherein older aircraft series are replaced by newer designs. Within the Army's helicopter fleet, AH-64 Apaches have largely replaced the AH-1 Cobra in the attack role and the UH-60 Black Hawk is rapidly replacing the UH-1 Iroquois in the Army's utility helicopter role. Historically, high-performance helicopters have exhibited high ground and sink speeds during crashes. In view of these findings, it is likely that some of the results observed in Table 10 are distorted by replacement.

The approach we took to investigate replacement was to divide the U.S. Army helicopter fleet into old (AH-1, CH-47, OH-58, OH-6, and UH-1) and new (AH-64 and UH-60) aircraft. For replacement to be a confounder, it must have an effect; that is, occupants of new aircraft must have a different injury profile. The overall risk of injury to the PC was significantly higher in the new aircraft group. Sixty-seven percent of PCs were injured in new helicopter mishaps versus only 48% of PCs in crashes of helicopters of older designs.

Table 12 compares injury profiles, restricted to PC station occupants, in potentially survivable crashes for old and new helicopter series by 5-year group. The proportion of injured crew members declined significantly in both old and new helicopters. In the older helicopter series, the proportion of injured crew members declined from 54.3% to 42.1%. While injuries to all body regions declined, the decline in head injury from 19.2% to only 10.9% possibly was causative in the decline in fatality risk from 5.3% to 2.3%. In the new aircraft, the number of mishaps during Period I was too small for the authors to draw any valid conclusions. However, overall injury rates fell from 68.3% in Period II to 63.4% in Period III. More significantly, the fatality rate fell between Period II and Period III.

After confirming that replacement was indeed confounding, its effect was controlled by the use of multiple logistic regression methods. Table 13 shows the results of multiple logistic regression models to adjust for helicopter type (old versus new), survivability (potentially survivable versus nonsurvivable), and occupant station (PC versus Other). Based on these models, we estimate a 42% decline in the overall injury risk between Periods I and II (1-0.578=0.422). The risk of head injury also declined by more than 51%, driven by statistically significant reductions in both face and brain injury. There was no significant decline in neck injury. Overall, the risk of torso injury also was unchanged but the risk of major organ injury did decline. This reflects a rise in the occurrence of back strains and strains since Period I. Interestingly, lower extremity injuries declined but not upper extremity injury.

To determine whether there had been a decline in injury severity, multivariate Analysis of Variance (ANOVA) methods were used to evaluate trends in the ISS. Controlling for occupant station, helicopter type, and survivability, the 5-year interval during which the crash occurred was statistically significant in the model. This was interpreted to demonstrate statistically difference in the ISS values between Period II and Period III. When the ANOVA models were used to predict the mean ISS for each Period, Period III was 5.1 points lower than Period II, controlling for helicopter type, survivability, and the occupant station.

The final analysis was to compare ISS scores. Since the 1980s, investigators have compared groups of injured patients in the context of the ISS. The ISS provides especially useful information on the impact of injury severity on survival. Table 14 compares the ISS values for each station in potentially survivable and nonsurvivable mishaps.

Results were analyzed using ANOVA procedures. This revealed a significant difference in the ISS values between Period II and III for pilot/copilot station in potentially-survivable mishaps. No differences were observed in the ISS values other occupants nor for the pilot/copilot in nonsurvivable mishaps. Subsequent analyzes demonstrated that the mean ISS for the pilot/copilot station occupant in potentially survivable mishaps declined from 14.15 to 10.10 in new aircraft and from 9.25 to 6.30 in old aircraft between Periods II and III. For other occupants, the ISS rose from 8.05 to 19.55 in new aircraft and fell from 10.70 to 4.84 in old aircraft.

5. DISCUSSION

Today, the U.S. Armed Services are forced to operate under extremely tight budget constraints when fielding new aircraft. As crashworthiness does not improve an aircraft's performance, increase its range, or reduce its operational cost, program managers are often hard pressed to justify its long-term benefits against the added cost and weight. We believe that crashworthiness is best justified by reductions in morbidity and mortality, but we needed a method of reliably predicting injury patterns in new helicopters--before they were built. To do this, we compared the injury patterns in ground-impact mishaps over the past 15 years. After controlling for key characteristics known to be associated with injury risk, clear trends emerged. We found that after adjusting for helicopter type, survivability, and occupant station, the risk of any injury had declined by 42% between 1980-84 and 1990-94. To our knowledge, this is the first cohort study conducted on U.S. Army helicopter mishaps which reports a decline in injury risks. This decline was found particularly for head injury, which declined by more than 50%.

But there is a question begged in all of this: what are the factors accounting for these differences? To investigate, we compared both injury profile and severity for all occupants. We determined that two factors played a role in the lack of significance in Table 6. The first was the severity of injury in nonsurvivable mishaps. Most, if not all, occupants in nonsurvivable mishaps are injured. The second was replacement. Newer aircraft have significantly higher injury risks. Therefore, as AH-64 and UH-60 helicopters entered the fleet, injury risk increased although the adjusted injury risk continued to fall.

These findings are confirmed by analysis of the ISS. There was a significant decline in the injury severity of the average pilot/copilot between 1985-89 and 1990-94. The overall ISS declined by 3.4 points while the ISS in potentially survivable mishaps declined by 2.8 points. Other occupants did not fare so well. The overall ISS for other occupants declined by 6.5 points while the ISS for other occupants in potentially survivable mishaps declined by only 0.07 points. A number of factors may be responsible for these differences. The U.S. Army began to field an improved version of its SPH-4 flyer's helmet, the SPH-4B, in 1990. The SPH-4B provides improved impact protection and is lighter than the helmet it replaced. As concussions have declined significantly, it is likely that the SPH-4B has played a role in the decline of head injuries previously cited. A second factor in the equation is the replacement of the earlier PVS-5 night vision goggle with the ANVIS. The ANVIS mount features a breakaway feature not found on the PVS-5. This feature virtually eliminated facial injuries associated with night vision goggle use.

It has been suggested that to be successful, programs must reduce mortality as well as morbidity. We estimate that by reducing the mortality risk from 4.6% in 1980-84, to 2.5% in 1985-89, and finally to 3.8% in 1990-94, 17 lives have been saved.

(611*4.6=28.1 -15=13.1; 449*4.6=20.7-17=3.7; 13.1+3.7=16.8)

6. CONCLUSIONS

This study has demonstrated that it is possible to reduce the risk of morbidity and mortality in rotary-wing mishaps. The most important cause of mortality, head injury, fell by more than 50%. Likewise, the risk of brain injury fell by 49%. While many possible causes of this decline are possible, major consideration should be given to improvements in helmet design and the Army's fielding of an improved flyer's helmet in 1990. Many of the changes in the SPH-4B were incorporated quickly into the existing SPH-4 helmet, which may explain the reduction in brain injury without a reduction in skull fractures.

7. REFERENCES

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Table 1. Criteria for categorizing U.S. Army aircraft mishaps in DA PAM 385-40.

Class	Total cost	Injury/cost threshold
A	More than	Fatality or total permanent
B	$200,000 to	1 permanent partial
C	$10,000 to	Loss of time from work

Table 2. Survey of U.S. Army Class A, B, and C ground-strike rotary-wing mishaps (1 January 1980 - 31 December 1994).

Total Mishaps		672	*Total Aircraft*		683
	Class A	430		Survivable	506
	Class B	111		Partially survivable	70
	Class C	142		Non-survivable	99
				Unclassified	8
Aircraft Series			*Aircraft occupants*		2,337
	AH-1	94		Pilot/Copilot/Gunner	1,342
	AH-64	31		All other	995
	CH-47	24			
	OH-58	190	*Injuries*		1,395
	OH-6	45			
	UH-1	235		Fatalities	401
	UH-60	64		Disabling	64
				Non-disabling	930

Table 3. Summary of study aircraft by time interval.

Series	Period I 80-84	Period II 85-89	Period III 90-94	Overall 80-94
AH-1	39	40	15	94
AH-64	0	10	21	31
CH-47	12	7	5	24
OH-6	16	17	12	45
OH-58	74	53	64	190
UH-1	125	69	41	235
UH-60	14	30	20	64
All	280	226	177	683

Table 4. Distribution of injuries and fatalities by aircraft series.

Aircraft	N	Injured	Killed
AH-1	188	165	33
AH-64	62	48	9
CH-47	243	156	81
OH-6	103	60	13
OH-58	413	254	53
UH-1	1,000	553	125
UH-60	328	223	87
Total	2,337	1,395	401

Table 5. Injury profiles in all aircraft: Overall (Jan. 1980 - Dec. 1994), Period I (Jan. 1980 - Dec. 1984), Period II (Jan. 1985 - Dec. 1989), and Period III (Jan. 1990 - Dec. 1994).

	Overall			Period I		Period II		Period III	
Population size	2,337			1,034		773		530	
	N	%	Rank	N	%	N	%	N	%
General (Multiple sites)	198	8.5	6	103	10.0	65	8.4	30	5.7
Head	638	27.3	2	256	24.8	259	33.5	123	23.2
Face	264	44.4	i	108	42.2	103	39.8	53	43.1
Skull	142	22.3	iii	63	24.6	44	17.0	35	28.5
Brain	254	39.8	ii	95	37.1	121	46.7	38	30.9
Neck	263	11.3	5	112	10.8	92	11.9	59	11.1
Cervical Spine	90	34.2		44	39.3	23	25.0	23	39.0
Torso	868	37.1	1	348	33.7	324	41.9	196	37.0
Thoracic Spine	112	12.9	ii	45	12.9	33	10.2	34	17.3
Lumbar Spine	86	9.9	iii	40	11.5	34	10.5	12	6.1
Spinal cord	47	5.4	iv	24	6.9	18	5.6	5	2.6
Major Organ System	395	45.5	i	156	44.8	164	50.6	75	38.3
Upper Extremities	435	18.6	4	189	18.3	168	21.7	87	16.4
Lower Extremities	578	24.7	3	246	23.8	214	27.7	118	22.2
Any Injury	1,385	59.3		619	59.9	475	61.4	291	54.9
Any Fatal Injury	401	17.2		159	15.4	154	19.9	88	16.6

Table 6. Estimates of the relative risk contrasting Periods I and III.

Injury	RR	CI_{95}	
Any Injury	0.816	0.661,	1.009
Head	0.918	0.718,	1.175
Face	0.953	0.674,	1.348
Skull	1.090	0.711,	1.670
Brain	0.763	0.516,	1.249
Neck	1.031	0.738,	1.440
Torso	1.031	0.930,	1.439
Major Organ System	0.928	0.687,	1.249
Upper Extremities	0.932	0.704,	1.233
Lower Extremities	0.917	0.715,	1.178

Table 7. Injury profiles, potentially survivable aircraft mishaps only: Overall (Jan. 1980 - Dec. 1994), Period I (Jan. 1980 - Dec. 1984), Period II (Jan. 1985 - Dec. 1989), and Period III (Jan. 1990 - Dec. 1994).

	Overall			Period I		Period II		Period III	
Sample size	1,957			897		611		449	
	N	%	Rank	N	%	N	%	N	%
General (Multiple sites)	68	3.5	6	36	4.0	16	2.6	16	3.6
Head	366	18.7	3	170	19.0	133	21.8	63	14.0
Face	225	61.5	i	92	54.1	91	68.4	42	66.7
Skull	72	19.7	iii	37	21.8	21	15.8	14	22.2
Brain	112	30.6	ii	56	32.9	44	33.1	12	19.0
Neck	187	9.6	5	86	9.6	60	9.8	41	9.1
Cervical Spine	35	18.7		22	22.9	5	8.3	8	19.5
Torso	563	28.8	1	258	28.8	180	29.4	125	27.8
Thoracic Spine	56	9.9	ii	30	11.6	10	5.6	16	12.8
Lumbar Spine	77	13.7	ii	37	14.3	29	16.1	11	8.8
Spinal cord	13	2.3	iv	10	3.9	2	1.1	1	0.8
Major Organ System	152	27.0	i	84	32.6	48	26.7	20	16.0
Upper Extremities	353	18.0	4	158	17.6	125	20.5	70	15.6
Lower Extremities	459	23.4	2	223	24.9	145	23.7	91	20.3
Injury	1,008	51.5		483	53.8	314	51.4	211	47.0
Fatality	73	3.7		41	4.6	15	2.5	17	3.8

Table 8. Relative risk estimates, traumatic injury for all occupants in potentially survivable U.S. Army rotary-wing mishaps.

Injury	RR	CI_{95}	
Head	0.683*	0.499,	0.936
Face	0.886	0.603,	1.301
Skull	0.735	0.393,	1.374
Brain	0.405*	0.215,	0.764
Neck	0.930	0.629,	1.375
Torso	0.923	0.725,	1.201
Major Organ	0.442	0.268,	0.731
Upper Extremities	0.846	0.622,	1.151
Lower Extremities	0.751*	0.570,	0.989
Any Injury	0.742*	0.591,	0.932
Fatal Injury	0.807	0.453,	1.438

* Statistically significant

Table 9. Population size: Pilot/copilot versus all other occupants stratified by survivability (ASMIS variable: SURV).

	Potentially	Non-survivable
Pilot/copilot	1,147	195
Other occupants	810	185

Table 10. Injury profiles, PC in potentially survivable aircraft mishaps only: Overall (Jan. 1980 - Dec. 1994), Period I (Jan. 1980 - Dec. 1984), Period II (Jan. 1985 -- Dec.1989), and Period III (Jan. 1990 - Dec. 1994).

	Overall			Period I		Period II		Period III	
Population size	1,147			491		364		292	
	N	%	Rank	N	%	N	%	N	%
General	33	2.9	6	14	2.9	11	3.0	8	2.7
Head	235	20.5	3	101	20.6	89	24.4	45	15.4
Face	156	66.4	I	54	53.5	67	75.3	35	77.8
Skull	49	20.9	iii	25	24.8	13	14.6	11	24.4
Brain	73	31.1	ii	36	35.6	29	32.6	8	17.8
Neck	123	10.7	5	59	12.0	39	10.7	25	8.6
Cervical Spine	23	18.7		16	27.1	5	12.8	2	0.8
Torso	323	28.2	1	139	28.3	108	29.7	76	26.0
Thoracic Spine	36	11.1	iii	19	13.7	8	7.4	9	11.8
Lumbar Spine	56	17.3	ii	22	15.8	23	21.3	11	14.5
Spinal cord	8	2.5	iv	6	4.3	1	0.9	1	1.3
Major Organ System	79	24.5	I	42	30.2	27	25.0	10	13.2
Upper Extremities	225	19.6	4	99	20.2	74	20.3	52	17.8
Lower Extremities	307	26.8	2	143	29.1	99	27.1	65	22.3
Any Injury	597	52.0		273	55.6	187	51.4	138	47.3
Fatal Injury	44	3.8		28	5.7	10	2.7	6	2.1

Table 11. Relative risk estimates for traumatic injury for PC station for potentially survivable rotary-wing mishaps only.

Injury	RR	CI_{95}	
Any Injury	0.692	0.516,	0.927
Head	0.681	0.468,	1.002
Face	1.071	0.681,	1.684
Skull	0.710	0.334,	1.466
Brain	0.346	0.159,	0.756
Neck	0.666	0.407,	1.089
Torso	0.860	0.619,	1.193
Major Organ System	0.369	0.182,	0.747
Upper Extremities	0.831	0.572,	1.206
Lower Extremities	0.673	0.410,	0.942

Table 12. Injury profiles among pilot/copilot station occupants in potentially survivable rotary-wing aircraft mishaps, stratified by aircraft class and year group of the mishap.

	Old Aircraft						New Aircraft					
	Period I		Period II		Period III		Period I		Period II		Period III	
Sample size	473		304		221		18		60		71	
	N	%	N	%	N	%	N	%	N	%	N	%
General	12	2.5	7	2.3	5	2.3	2	11.1	4	6.7	3	4.2
Head	91	19.2	60	19.7	24	10.9	10	55.6	29	48.3	21	29.6
Neck	59	12.5	27	8.9	15	6.8	0	0.0	12	20.0	10	14.1
Torso	129	27.3	86	28.3	50	22.6	10	55.6	22	36.7	26	36.6
Upper Extremities	92	19.5	53	17.4	29	13.1	7	38.9	21	35.0	23	32.4
Lower Extremities	136	28.8	74	24.3	42	19.0	7	38.9	25	41.7	23	32.4
Injury	257	54.3	146	48.0	93	42.1	15	83.3	41	68.3	45	63.4
Fatality	25	5.3	8	2.6	5	2.3	3	16.7	2	3.3	1	1.4

Table 13. Multivariate relative risk estimates for injury in US Army helicopter mishaps controlling for survivability, aircraft type, and occupant station.

Injury	RR	CI_{95}	
Any Injury	0.578	0.451,	0.741
Head	0.486	0.355,	0.665
Face	0.616	0.411,	0.923
Skull	0.816	0.521,	1.279
Brain	0.510	0.313,	0.831
Neck	0.707	0.474,	1.055
Torso	0.796	0.609,	1.042
Major Organ System	0.547	0.350,	0.858
Upper Extremities	0.748	0.547,	1.024
Lower Extremities	0.736	0.553,	0.979

Table 14. A comparison of ISS values: Pilot/copilot versus all other occupied stations by survivability.

Period	Station	Mishap Class	Mean	STD
2	Pilot/ Copilot	Overall	20.65	27.92
		Potentially	10.07	16.51
		Non survivable	67.62	17.95
	Other	Overall	24.30	30.19
		Potentially	9.87	16.10
		Non survivable	68.88	17.0
3	Pilot/ Copilot	Overall	17.20	26.89
		Potentially	7.23	13.58
		Non survivable	70.13	15.74
	Other	Overall	17.77	27.93
		Potentially	9.80	19.87
		Non survivable	65.85	20.37