Cost of Military Eye Injury and Vision Impairment Related to Traumatic Brain Injury: 2001–2017

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ABSTRACT Introduction: Annual incidence of eye injury among members of the US armed services is high and can cause vision impairment and blindness. Traumatic brain injury is also associated with visual function. An estimate of the cost of treatment, benefits for those who are disabled, productivity loss for those with reduced vision function, and the cost of replacing and retraining others to take the responsibility of those who are discharged from the military will provide a benchmark to which to compare the cost of new methods to prevent, diagnose, mitigate, treat, and rehabilitate vision loss after injury. Materials and Methods: The modeling exercise used a combination of data from military websites, results previously published in the literature, and from other government websites. Data were combined to estimate the number of superficial injuries, the number of injuries with a high risk of blindness, the cost of medical care, the cost of disability benefits, and the cost of potential lost productivity. Results: Over the time period in question, the average annual incidence of eye injury was 15,681 with 304 hospitalized and 298 at high risk of blindness. There were 4,394 annual TBI cases without injury to the eye but with visual impairment. The total cost of treatment, benefits, and potential lost productivity is $2.4 billion annually; $1.9 billion is associated with TBI. $11.7 million is associated with replacing and retraining members of the military. Conclusions: The cost of eye injury and vision dysfunction in the military is substantial. The cost of potential productivity loss associated with TBI makes up the largest proportion of total costs. Developing new standards to enhance eye safety and limit TBI could be cost-effective. Cost analyses such as this study should prove helpful in determining the economic return on investments to prevent, mitigate, treat, and rehabilitate visual system injury.

INTRODUCTION

Ocular trauma and the related vision dysfunction are important vision public health issues in the general population in the USA. In particular, superficial eye injuries (annual incidence 100.7/100,000 population), extraocular foreign bodies (annual incidence 53.6/100,000 population), contusions of the eye and adnexa (annual incidence 27.3/100,000 population), ocular adnexal open wounds (annual incidence 26.3/100,000 population), and orbital floor fractures (annual incidence 8.9/100,000 population) comprise the top five causes of ocular trauma that present to civilian emergency departments.[1] Visual system damage (from eye and/or brain trauma) is also a public health issue in the military and among veterans, as evidenced by the voluminous data collected by the Departments of Defense and Veterans Affairs through the Vision Center of Excellence's trauma registry (https://vce.health.mil/), i.e., the Defense and Veterans Eye Injury and Vision Registry (personal communication with Ms. Helen White, Director of VCE Informatics & Information Management).

The most recent peer-reviewed journal publication on trends in military eye injury and related dysfunction is from the early part of the decade.[2] As the US military presence in different regions of the world and the types of conflicts in which the military is engaged has evolved over the past eight years, the potential for ocular trauma and traumatic brain injury (TBI) that can result in visual dysfunction has changed. The goal of the present analysis is to update the incidence data and update literature that estimated the related costs incurred by the government and individuals. Specifically, we aim to estimate the costs of eye injury including treatment; costs related to unemployment and loss of earnings for vision impairment; costs related to rehabilitation, unemployment, and loss of earnings for blindness; costs to family for blindness; VA costs; costs of recruiting and retraining service members after loss from blindness; and costs related to vision dysfunction from TBI. Having this type of cost information will inform resource allocation decisions (i.e., cost-benefit analyses) for the Military Combat Eye Protection Program and other efforts to prevent eye injury.

METHODS

The objective is to calculate the average annual incidence of eye injuries of differet types and estimate the amount of consequent visual impairment and cos for the US armed forces. Ocular injury requires treatment and can lead to vision impairment. Many of those who experience TBI, even when mild, will experience visual impairment as a result.[3] These individuals will also experience decreased lifetime income from unemployment and lower earnings among those who are employed; excess medical care costs; and excess family

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support. Furthermore, all those who suffer with visual impairment or a blind eye will need to be replaced, encumbering training resources with additional costs.

Data on incidence of eye injury are required to begin the cost calculation. Hilber provided the seminal report on the number of incident eye injuries among the active component of the US military covering the years 2000–2010.[2] Incidence data are available online from 2000 through the first quarter of calendar year 2017. Data through 2015 have been complied into annual reports while the data from the start of 2016 onward are in quarterly format. All reports can be found on the website of the US Army Public Health Command, and are titled (by appropriate time period) US Department of Defense Active Duty Eye Injury Summary Calendar Year 2002 (as one example) and can be found at https://phc.amedd.army.mil/Periodical%20Library/DoD2002.pdf).

The data from 2000–2010 nearly match what was published in Hilber. For consistency, we will use only data from the current online sources. The data used from these publications included the number of ambulatory and hospitalized cases. We counted all cases whether the eye injury was the primary reason for care or not. Deployment treated cases, i.e., less advanced level eye care provided at locations such as combat aid stations were excluded. While our ability to cost them out is hampered by a lack of relevant data, we believe these costs would be relatively modest because they are associated with only limited treatment capabilities. The reports also indicated whether the cases were superficial (all others were assumed to be non-superficial) and whether the injuries were judged to be associated with a high risk of blindness. Notably, superficial eye injuries include corneal and conjunctival abrasions and external foreign bodies. This case definition was developed by the Armed Forces Health Surveillance Branch (AFHSB) and the Tri-Service Vision Conservation and Readiness Program (TSVCRP) at the Army Public Health Center (APHC).[4,5]

To calculate the additional impact of vision dysfunction related to trauamatic brain injury, individuals who had an eye injury and a TBI were assumed to already be captured by the eye injury data above. Brahm et al[6] reported on the prevalence of ocular injury among TBI patients with moderate or more severe injury and TBI patients with mild injury. The weighted average for this dual diagnosis across all TBI is 11.8%. The incidence of TBI from the start of 2000 through the second quarter of 2017 was obtained from Defense and Veterans Brain Injury Center (DVBIC) reports. While TBI can be classified as mild, moderate, severe, penetrating, and not classifiable, the focus of this analysis is the total incidence. Cockerham et al[7] reported on vision impairment among military service individuals who had TBI. Several studies suggest that the proportion of cases of TBI across all levels of severity that result in some vision impairment range from 66% to 97%, where 75% was the most common figure cited.[6,8–11] Congdon et al[12] reported a 2.76% prevalence of blindness and permanent visual impairment in the entire population. The Medical Expenditure Panel Survey responses indicate an 8.8% prevalence of self-reported vision impairment or blindness.[13] Thus, assuming that the self-report is 100% sensitive, it follows that the proportion of clinically measurable vision impairment from TBI was 31% of the self-reported cases.

To calculate the costs of superficial eye injuries, data were drawn from Islam et al.'s report on the cost of treating a variety of injuries.[14] The figure was adjusted for inflation to be appropriate for the start of the year 2017 using the Bureau of Labor Statistics series on medical care services for all urban consumers. Approaches used for treatment may have changed since Islam's research was conducted, but there are no more recent references on the US cost of treating superficial ocular injury since then.

To calculate secondary costs related to ocular injury, we used data Islam et al[14] reported on the proportion of superficial ocular injuries resulting in a workers' compensation indemnity payment (5.14%) and the average number of days of payment (8.5). A source on VA compensation indicated an annual salary of $46,647 in 2006 for those with service-connected disabilities.[15] This was inflation adjusted using the general consumer price index.

To calculate the cost of non-superficial eye injuries, data were drawn from Buckingham et al.'s report on costs.[16] While costs were reported by service branch, for calculations in this paper the costs were averaged across all branches. Buckingham et al reported the money spent from 1988 to 1998, but did not make clear whether inflation adjustments were made;[16] as a result, calculations in this paper were made assuming that the figures were reported as 1998 dollars and inflation-adjusted using data from the Bureau of Labor Statistics medical care series for all urban consumers. For those with non-superficial injury but not permanent vision impairment, this was the only cost.

To transition from the number of eye injuries and related costs to number of resulting cases of vision impairment and the resultant costs, data were drawn from the American Academy of Ophthalmology reports on eye injuries. Houtenville provided data on the decrease in employment for the visually impaired.[17] Rein et al[18] reported on reduced earnings for the visually impaired-but-not-blind and the ratio was applied to the annual earnings figure used earlier. Family support was also calculated. Lifetime excess medical care was based on a $1,412 difference per person annually reported by Frick et al[13] and inflation-adjusted using the Bureau of Labor Statistics medical care for all urban consumers' series.

To estimate the number of cases of resulting blindness, data were drawn from Kuhn et al.'s report on the proportion of those with injuries judged at high risk of blindness for whom the injury resulted in blindness.[19] Thach et al[20] reported on the proportion of cases with blindness that resulted in bilateral blindness. The VA Blindness Rehabilitation Center costs per year in 2006 US dollars was reported in Stroupe et al.[21] The VA Blindness Rehabilitation Center costs per year are $38,627

in 2006 US dollars.[21] As the authors had used the general consumer price index in their calculations, this was also used to inflation-adjust the reported costs to 2017 dollars.

Absenteeism is also an issue for those with ocular injury. The percentage of patients missing work secondary to any eye injury is 70.16%.[14] The average number of days missed was 2.8.[14] Overall, the decrease in employment for the visually impaired is 6.5%. Furthermore, the earnings for the visually impaired-but-not-blind are 70.3% of those with normal vision, a loss of 29.7%.[18]

Changes in work status are a further issue for those who are blind as a result of an eye injury. Houtenville reported the employment rate for blind compared with those with normal sight.[17] The remaining working years are calculated taking 29 as the average age at injury as reported by Hilber[2] and assuming a retirement age of 65. Using a 3% discount rate and the average annual salary data with appropriate general consumer price index inflation adjustments, the present value of the remaining working years is calculated.

In addition to the costs of immediate treatment of the eye injury, those with resultant vision impairment or blindness face higher medical care costs on average. Frick et al[13] estimated that the excess cost of medical care used by blind individuals compared with normally sighted individuals is $2,157 per year in 2007 dollars. The lifetime excess expenditures for all blind individuals were calculated by factoring in the life expectancy (using data from http://www.worldlifeexpentacy.com), applying a 3% discount rate, applying an inflation adjustment to the figures using the medical care services price index (MCSPI), and assuming that the difference in expenditures remains the same as a blind individual ages.

Those who are blind often require assistance at home from family or friends that is not compensated. Keeffe et al. reported the annual cost of extra family support as $710,[22] which after inflation adjustment using the general consumer price index is US$812. The present value of lifetime expenditures on family support was calculated using the same discount rate and life expectancy as was used for excess medical costs.

Armed services personnel who suffer eye injuries resulting in vision impairment or blindness can no longer be deployed. A 2011 GAO document reported the cost of recruiting and retraining of the replacement to replace members of the armed forces who were separated in an untimely manner (although not for injury).[23] Costs were inflation adjusted to 2017 and applied to those who are lost to a combination of bilateral blindness, unilateral blindness, or uncorrectable vision impairment each year. It cost $185.6 million (in 2011 US$) to replace 3664 individuals. Inflation adjusting to 2017 monetary units, the cost per armed services member who is lost because of blindness or vision impairment is $58,253.

The Department of Veterans Affairs provides benefits to those who become blind as a result of service injuries. Blind veterans are eligible for a one-time housing payment of up to $77,303 (https://www.everycrsreport.com/reports/R44837.html; accessed December 04, 2017), an automobile allowance (for a driver) of $20,235 (https://www.everycrsreport.com/reports/R44837.html; accessed December 04, 2017), and a monthly allowance of $2,916 (https://www.everycrsreport.com/reports/R44837.html; accessed December 04, 2017).

To calculate the costs related to vision impairment from TBI required assumptions. Lifetime per-service member costs of visual impairment that is not bilateral blindness were calculated assuming that the costs related to vision impairment are the same when it results from TBI either with or without ocular injury. The cost per-service member figure was multiplied by the number of cases of visual impairment related to TBI without ocular injury.

The total time frame examined was from 2000 to 2017Q1. The costs described above are the average 1-year costs based on the average incidence of injury over that time. There is no way to project whether future injuries and costs will be similar or different. Calculations were made for the present value of the projected VA benefits for the remainder of the lives of all service members with ocular injuries in the 17.25 years under study as well as for service members with vision impairment due to TBI.

RESULTS

The total number of incident injuries from the beginning of 2000 through the end of March 2017 included 270,505 ambulatory and another 5,237 hospitalized. The number of superficial injuries was 193,658 ambulatory and 701 hospitalized. The number of high-risk of blindness injuries from the combination of ambulatory and hospital cases was 6,087 (Table IA).

The incidence of TBI from the start of 2000 through the second quarter of 2017 as 370,688. As noted in the Methods section, 11.8% were assumed to also have an ocular injury and be counted elsewhere, leaving 326,920. Of these, 75% were assumed to self-report visual dysfunction or impairment. Thus, approximately 245,000 service men and women had a complaint but no direct ocular injury.

TABLE IA. Incident Eye Injury

Type of Eye Injury	2000–2017Q1 Ambulatory	2000–2017Q1 Hospitalized	2000–2017Q1 Total
Total	270,505	5,237	275,742
Superficial	193,658	701	194,359
Non-Superficial	76,847	4,536	81,383
High risk of blindness	5,144	943	6,087
	Annualized	**Hospitalized**	**Annualized**
Total	15,681	304	15,985
Superficial	11,227	41	11,267
Non-Superficial	4,455	263	4,718
High risk of blindness	298	55	353

TABLE IB. Incident TBI

Category of Injury	Number
Incident TBI from 2000 to 2017Q2	370,688
Incident TBI without eye injury 2000–2017Q2 (estimated)	326,920
Incident TBI without eye injury with some visual complain 2000–2017Q2 (estimated)	245,190
Incident TBI without eye injury with clinical visual impairment 2000–2017Q2 (estimated)	76,900
Annualized TBI without eye injury with clinical visual impairment (estimated)	4,394

Using the 31% ratio of self-reported cases to clinically measurable cases of vision impairment, 76,900 individuals are calculated to have some clinical level of vision dysfunction over the 17.5 years. Dividing by 17.5 (the incidence data include 2000 through the second quarter of 2017 unlike all other incidence data that go through only the first quarter of 2017), we find 4,394 cases per year (Table IB). The cost of treating a variety of ocular injuries was reported as $196.50 in 1998 US dollars. The inflation-adjusted cost of treating each injury is calculated as $400. The total cost of treating 11,267 superficial eye injuries per year is $4.51 million. The cost for 8.5 days of indemnity payment (based on a 250-day work year) for the service members with superficial eye injuries is calculated at $746,000 assuming an indemnity of 66.7% of the value of the inflation-adjusted wage. The value of missed work time is calculated to be $5.0 million. The sum of costs for military-related superficial eye injuries for 2017 is approximately $10.3 million. The inflation-adjusted weighted average cost per injured service member is $11,320. The annual cost of treating incident injuries is $53.4 million.

The average of the proportion blind from four different types of conditions associated with a high risk of blindness in Kuhn et al is 43%.[19] There are 17 bilaterally blind people per year (11.2% of 43% of the 353 each year at high risk of blindness). The inflation-adjusted rehabilitation cost is $47,029. The annual cost of rehabilitation is $798,308. The lifetime excess expenditures for all the blind individuals are $1.3 million. Assuming the annual cost of extra family support to be $710 and discounting at 3%, this adds $364,000 to the total burden. The total value of the loss of economic productivity for these eight service members was calculated at $8.5 million. Projecting the VA monthly payment over the remaining work years (assuming that other benefits become relevant at normal retirement age) the total accumulated would be $15.0 million. The total lifetime costs that are incident annually for bilaterally blinded individuals is $79.5 million (Table II).

Of all eye injuries, 16.9% of result in moderate impairment and 7.0% result in blindness. Taking 16.9% of the 93.0% not-blind and multiplying that by the number of non-superficial injuries less the number of blind cases already calculated, we obtain a number that is projected for vision impairment of 854 per year. The total lifetime loss of income for those among the 854 visually impaired cases who are unemployed but would not have been otherwise is $71.0 million. For those who are visually impaired but still working, $266.6 million in wages were lost. An additional $5.1 million in family support was calculated. The total inflation adjusted. Lifetime excess medical care is $31.9 million. This results in a total cost of $375 million in lifetime expenses for those who are visually impaired but not blind (Table III). For the 201 individuals who are lost to a combination of bilateral blindness, unilateral blindness, or uncorrectable vision impairment each year, the costs are $11,723,787.

TABLE II. Cost for Non-superficial and High Risk of Blindness Injuries

Item	Cost in US $2017
Treating Non-superficial Injuries	53,405,091
Rehabilitation for bilaterally blind individuals	798,308
Lifetime income loss for bilaterally blind individuals	8,546,370
Lifetime excess medical care costs for bilaterally blind individuals	1,317,992
Lifetime excess costs of family support for bilaterally blind individuals	364,373
Lifetime VA payments for housing, automobile, monthly allowance	15,198,295
Total	$79,450,429

TABLE III. Cost for Visual Impairment from Ocular Injury Not Resulting in Bilateral Blindness

Item	Cost in US $2017
Excess unemployment for visually impaired	70,954,043
Loss of income for visually impaired who are still working	266,579,768
Family support for visually impaired	5,155,983
Excess medical care for visually impaired	31,887,432
Total	374,537,226

The lifetime per-service member costs of visual impairment that is not bilateral blindness sum to $438,823. Multiplying the cost per-service member figure by the number of cases of visual impairment related to TBI without ocular injury (4,394) we calculate a total burden of $1.93 billion. The total incident cost of eye injury and vision impairment related to TBI in the military each year is $2.40 billion (Table IV).

The total cost to the economy of all ocular injury and all vision impairment related to TBI is $41.47 billion. Of the total, the costs incurred in the first year (all for superficial injury, initial medical care for non-superficial injuries, and rehabilitation for bilateral vision impairment) are $1.314 billion. This is money that has already been paid. The present value of the projected VA benefits for the remainder of the lives of all service members with ocular injuries in the 17.25 years under study are $259 million. The present value of the projected costs to the remainder of the economy over the remaining lifetimes of the

TABLE IV. Summary of Costs Related to Eye Injuries and Visual Impairment from TBI in 2017 US Dollars

Item	Cost in US $2017
Costs of treating superficial eye injuries	10,286,129
Costs of non-superficial and high risk of blindness eye injuries	79,450,429
Costs for visual impairment from ocular injury not resulting in bilateral blindness	374,537,226
Costs for replacing and retraining those discharged for visual impairment or blindness	11,723,787
Costs of TBI resulting in visual impairment	1,928,322,239
Total	2,404,319,811

service members with eye injuries or vision impairment due to TBI is $41.47 billion.

DISCUSSION

Eye injury in the military and TBI with the related visual dysfunction has a substantial economic impact each year and over the lifetime of the members of the armed services who are impacted. The costs associated with TBI-related cases of visual dysfunction dominate total costs. Aside from the TBI cases, the largest impact at the population level comes from the cases of visual impairment that are not bilateral blindness. While these are less costly than the costs of blindness, that is a function of the higher incidence while blindness has a higher economic impact per member of the armed services. Both have an impact on working, medical care costs, and the need for family support. Blindness also has rehabilitation costs and benefits from the Department of Veterans Affairs. While superficial eye injuries cost in the millions of dollars per year to treat, this cost is comparable to the cost of replacing and retraining service members to replace those lost to visual impairment.

While the data on the incidence of eye injuries and TBI are high quality, the number of assumptions that go into any modeling exercise is quite large. Two critical assumptions for this study that deserve further exploration are improved documentation of the number of TBI cases who also have an ocular injury and a cross-tabulation between cases that may be superficial but are still associated with a high risk of blindness. In the latter case, there are not expected to be a large number of these, but clear documentation will allow for better assessment. A study of the sensitivity and specificity of self-reported vision impairment with clinical visual impairment would also help to allow us to translate the report of visual dysfunction into real impact. A further limitation is using primarily costs for civilians and costs of blindness and visual impairment for those without other significant injury. These give a starting point for discussion, but study of the actual economic impact of blindness and visual impairment for those with significant other injuries would enhance the precision of these estimates.

It should also be mentioned that the authors have not attempted to estimate the direct costs to the patient and to the government stemming from legal actions, such as when patients must acquire representation to contend with issues such as possible eviction, amounts of VA, workers' compensation or social security benefits or levels of disability ratings. Although it would be extremely difficult to provide an estimate of these costs, it is almost certain that they would add substantially to the numbers already provided. Finally, the authors recognize that there are also indirect costs stemming from service personnel who acquired visual disability such as expenses to train replacements.

In light of the cost of eye injury and TBI-related vision dysfunction, the armed services leadership and the members would benefit from additional research on ocular safety, the prevention of TBI, and the importance of treating all eye conditions in ways that minimize disability. Preventing TBI would save significant resources for causes other than visual dysfunction as well.[24] Finally, cost analyses such as this study should prove helpful in determining the cost-benefit ratio of efforts to prevent, diagnose, mitigate, treat, and rehabilitate visual system injury.

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