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Lifetime Cost of Abusive Head Trauma at Ages 0–4, USA

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Abstract

This paper aims to estimate lifetime costs resulting from abusive head trauma (AHT) in the USA and the break-even effectiveness for prevention. A mathematical model incorporated data from Vital Statistics, the Healthcare Cost and Utilization Project Kids' Inpatient Database, and previous studies. Unit costs were derived from published sources. From society's perspective, discounted lifetime cost of an AHT averages $5.7 million (95% CI $3.2–9.2 million) for a death. It averages $2.6 million (95% CI $1.0–2.9 million) for a surviving AHT victim including $224,500 for medical care and related direct costs (2010 USD). The estimated 4824 incident AHT cases in 2010 had an estimated lifetime cost of $13.5 billion (95% CI $5.5–16.2 billion) including $257 million for medical care, $552 million for special education, $322 million for child protective services/ criminal justice, $2.0 billion for lost work, and $10.3 billion for lost quality of life. Government sources paid an estimated $1.3 billion. Out-of-pocket benefits of existing prevention programming would exceed its costs if it prevents 2% of cases. When a child survives AHT, providers and caregivers can anticipate a lifetime of potentially costly and life-threatening care needs. Better effectiveness estimates are needed for both broad prevention messaging and intensive prevention targeting high-risk caregivers.

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Compliance with Ethical Standards

Conflicts of Interest The National Center on Shaken Baby Syndrome (NCSBS) and RG Barr jointly registered the trademark for the Period of PURPLE Crying. Graham Consulting Ltd. consults and provides grants for child abuse prevention and child development programs. It owns the royalties that are a minor share of the net profits from the sale of the Period of PURPLE Crying program. RG Barr and M Barr sit as two members of its uncompensated Board of Directors. M Barr was the former Executive Director of the NCSBS, a 501(c)3 non-profit organization. Both are uncompensated members of the International Advisory Board of the NCSBS. The other authors have no financial relationships or potential conflicts of interest relevant to this article to disclose.

Ethical Review All protocols and instruments for the broader study that included this paper were approved by Pacific Institute for Research and Evaluation's institutional review board. The study was performed in accordance with the approved protocol and with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all individual participants included in the study.

Keywords

Child abuse; Shaken baby syndrome; Economic analysis; DALY; Breakeven

Introduction

The American Academy of Pediatrics defines abusive head trauma (AHT) as any injury intentionally inflicted on the head or brain of a young child (Christian et al. 2009). The term encompasses shaken baby syndrome and other forms of child abuse, with a cutoff age below 5 years recommended for case ascertainment (Parks et al. 2012). AHT is a devastating and potentially lethal form of child abuse that is a tragedy for the young child, the child's family, and society in general.

The costs of AHT are not only financial but include the destruction of families and the failure of society's obligation to protect those who are defenseless against abuse. Medical costs attributable to AHT in the 4 years following diagnosis average approximately $48,000 per affected child (with all costs in this paper in 2010 dollars) (Peterson et al. 2014). The only comprehensive analysis of the costs of an AHT case comes from New Zealand. There, costs per AHT survivor averaged USD$725,300 (as detailed in the online supplement) (Friedman et al. 2012). Across all forms of child maltreatment in the USA, average lifetime cost per maltreatment survivor is an estimated $210,000, excluding quality of life and lost work costs (Fang et al. 2012). AHT is a particularly severe form of child physical abuse, which means that costs for AHT victims are likely to be even higher. However, no study has comprehensively estimated lifetime costs of AHT in the USA.

This study aimed to estimate the total lifetime costs of fatal AHT and of non-fatal AHT by severity—mild, moderate, and severe—including lost quality of life and lost work costs, as well as the share of costs paid by government sources. Drawing on previous prevention cost estimates, this study also provides insight into the effectiveness required for AHT prevention to break even.

The study provides lifetime costs per incident, which are the appropriate problem cost estimates for analyzing the economics of prevention. It follows quality guidelines for producing benefit-cost data in National Academies of Sciences, Engineering, and Medicine (2016), notably in its choice of method to place a dollar value on the disability-adjusted life year (DALY) burden resulting from the problem. It also complies with the Consolidated Health Economic Evaluation Reporting Standards (Husereau et al. 2013).

Methods

We used the Centers for Disease Control and Prevention's definition of AHT: an injury to the skull or intracranial contents of an infant or child under age 5 due to inflicted blunt impact or violent shaking (Parks et al. 2012). We compiled existing information from a variety of sources as inputs for a mathematical model to project lifetime cost of AHT. Table 1 reports model inputs and sources. The online supplement shows the formulas that combined the inputs. We report lifetime cost per case of mild, moderate, and severe AHT;

the portion of costs paid by government sources; the cost of AHT per US live birth; and the effectiveness needed for AHT prevention to break even.

Incidence

We used published AHT case count estimates, including a distribution of non-fatal AHT by severity (Miller et al. 2014). Drawing on the expertise of an informal physician panel, the published study defined mild cases as ones with no long-term sequelae. It defined moderate cases as ones with no long-term effects except one and only one of (1) use of one anti-epileptic medication, (2) use of an arm brace or another assistive eating device and/or needing shoes with ankle-foot orthopedics, or (3) insertion of a brain shunt. Interview reports by caregivers or medical providers for a convenience sample of 120 severe AHT victims showed that 116 victims had retinal damage or took multiple anti-epileptic drugs. The study used those two markers to estimate which cases were severe in population-based administrative data sets, which we note means it may have misclassified a modest 3% of severe cases (4/120) as mild or moderate. Its AHT case counts came from 2009 Vital Statistics mortality data, 2009 Healthcare Cost and Utilization Project (HCUP) Kid's Inpatient Database (KID) admissions, and 2003–2011 Truven Health Marketscan® claims data from private insurers and Medicaid plans (Miller et al. 2014). The estimates assumed that each inpatient admission reported in HCUP KID represented a unique AHT victim. Miller et al. (2014) computed its estimates for non-admitted cases by multiplying the admission count times ratios computed from the distribution of place of treatment for 1209 AHT cases identified in longitudinal Marketscan data. For every AHT case admitted to the hospital, 0.894 cases were treated in the ED and released and 0.340 cases were not treated at hospitals within 2 days after initial diagnosis (which suggests that they were latent cases not diagnosed during the acute phase) (Peterson et al. 2014). So, only counting hospital admissions would have underestimated the rate of AHT. Table 1 provides details of these computations.

Except in sensitivity analysis, following Miller et al. (2014), we increased observed AHT incidence estimates to account for latent AHT survivors not treated at hospitals within 2 days of diagnosis (Peterson et al. 2014). We believe that by the time these survivors are correctly diagnosed in the medical system, their AHT is no longer in an acute phase that would benefit from inpatient care. Though such treatment circumstances may be surprising to clinicians familiar with AHT, this finding—and our corresponding increased estimate of AHT incidence—seems credible for several reasons. First, AHT is closed head trauma. It often is not visible to the untrained eye. Indeed, one study found that pediatric emergency physicians missed 31% of AHT diagnoses at first visit, sometimes failing even to consider TBI in their differential diagnosis (Jenny et al. 1999). Second, a shaken infant typically suffers a concussion-like brain injury that causes it to stop crying, creating a positive feedback cycle with the abuser rewarded by improved infant behavior (Barr 2012). Lack of external signs of injury may result in repeated shaking in more than half of AHT babies and a lengthy delay in seeking medical care (Adamsbaum et al. 2010). Third, in Wales, Cobley and Sanders (2007) found that in 20% of AHT cases where police filed charges (9.4% of all cases), the charges included a charge of medical neglect for failing to get prompt medical

attention for the child. Supplemental Table 2 shows that these latent cases account for 28% of total annual costs.

Survival and Mortality

We used published estimates of mortality impacts of AHT, with 7% almost immediately fatal (Miller et al. 2014). Those estimates assumed that 5% of severe AHT survivors died within the first 6 months following hospital discharge. Thereafter, for severe AHT survivors, the study applied a mortality rate based on traumatic brain injury (TBI) mortality data (Strauss et al. 1998) of 5% per year for the first 8 years (a cumulative standardized mortality rate [SMR] for children aged 1 to 8 that averages 44.7 times the normal rate without TBI from the 2009 US life table (Arias 2014)) and 4% per year beyond 8 years following abuse (a SMR of 21.0 times the norm for individuals aged 9 to 45). The mortality data (Strauss et al. 1998) provided smaller SMRs of 1.7 times the norm following moderate TBI and 1.06 times the norm following mild TBI.

Costs and Disability-Adjusted Life Years

All costs and DALY losses beyond the first year following the abuse were converted to present values using a 3% discount rate (Neumann et al. 2016). Because the case counts are from 2010, for consistency, all costs are presented as 2010 US dollars, inflated using appropriate components of the Consumer Price Index and Employment Cost Index (Obama and Advisers 2014).

By place of treatment (inpatient, ED treated and released, physician's office or clinic for latent cases), we assessed AHT burden from a societal perspective in the following cost categories: medical, special education, child protective and criminal justice, and adult mental health services; perpetrator work loss if incarcerated; short-term work loss of caregivers; loss of earning capacity of the abused; and DALYs. Conceptually, DALYs capture the earning capacity loss. Using a widely accepted method (Blincoe et al. 2014), we stated that loss separately to let readers better understand the burden AHT places on victims. Separately stating the earning loss component does not imply that AHT changes net earnings in the US economy.

We applied average *medical* costs of $47,952 (95% CI 40,219–55,685) in the first 4 years following non-fatal AHT based on a recent analysis of medical claim data among AHT victims (Peterson et al. 2014). Because moderately and severely injured AHT victims require lifelong prescription drugs, medical care, or medical devices, we assumed that their increased medical cost of $1501 (95% CI $350–$2652) in the fourth year following the abuse would persist throughout the child's life. For mild cases, the pediatrician on our team estimated that increased cost only would persist through age 18. To estimate medical care cost for AHT fatalities, we multiplied reported medical cost estimates by place of death (untreated, in-hospital, etc.) by the number of AHT deaths by place of death reported in Vital Statistics data (Finkelstein et al. 2006). We computed medical costs per AHT fatality in ED and inpatient hospital settings by applying HCUP's cost-to-charge ratios (HCUP 2015) to charges for deceased AHT discharges in HCUP KID and selected state ED discharge data. We then applied diagnosis-specific multipliers that we derived from Truven Health

Marketscan® data to add associated physician or professional fees, which were not included in HCUP financial data.

Special education costs came from 1999 to 2000 data (Chambers et al. 2003), inflated to 2010 dollars by multiplying these costs by the cost per pupil in US schools in 2010 divided by the cost in 1999 (National Center for Educational Statistics 2013). We applied estimated costs of $34,280 annually for special education per child with severe AHT, $28,219 annually per child with moderate AHT, and $21,367 annually per child with mild AHT (Chambers et al. 2003). From these estimates, we subtracted the $11,184 average cost of education per pupil in the USA (including pupils with disabilities) (National Center for Educational Statistics 2013).

Non-fatal AHT is legally chargeable as assault, while fatal AHT is chargeable as homicide. We used national average unit costs of *child protective*, *victim*, *police*, *adjudication*, and *sanctioning (prison or parole) services* from a previous study (Miller and Hendrie 2014). Data were not available to differentiate these costs by AHT severity.

We used published *mental health care costs* for family and friends of a homicide victim (Miller and Hendrie 2014). On average, homicide puts 2.1 people into mental health treatment (Cohen and Miller 1998). We assumed that, on average, severe AHT would impose the same mental health burden while moderate AHT would put one adult into treatment at a comparable level of service.

Work loss cost estimates included lost wages, fringe benefits, and the value of lost household work. To value work loss, we started from published estimates of lifetime work loss due to death or permanent disability and of work loss due to injury by diagnosis (Blincoe et al. 2014; Finkelstein et al. 2006; Lawrence et al. 2011; Lawrence et al. 2000). Less than 40% of severe AHT victims are expected to survive into adulthood. Their functional deficits, as reported in a recent survey (Miller et al. 2014), leave victims totally and permanently disabled, so their work loss is equivalent to that of a fatality. For moderate and mild AHT, we assumed that a caregiver at a female wage level would lose a day from work caring for a homebound or hospitalized child for each day that an adult suffering a comparable injury would have been unable to work (Blincoe et al. 2014; Lawrence et al. 2000).

Rather than use average earnings in calculating wage losses of victims, their post-injury caregivers, and perpetrators, we tailored estimates. First, we estimated the average annual earnings of the parents of AHT victims. The estimate started from national estimates that in 2000–2009, the odds of AHT were 2.81 times higher for children on Medicaid/CHIP (95% CI 2.52–3.15) and 1.37 times higher for self-pay children (95% CI 1.05, 1.78) than for children covered by private insurance or other payers (Niederkrotenthaler et al. 2013). We used unadjusted odds ratios because adjusted ones (2.78 and 1.68, respectively) included a non-significant but collinear variable about residence in a zip code below median income. We combined a national count of children by source of health care coverage in 2010 (Bloom et al. 2011) and a national estimate of household income distribution by source of child health care coverage in 2010 (Coyer and Kenney 2013) to estimate household income in 2010 dollars. Household income averaged $24,743 for children on Medicaid, $49,200 for

uninsured children, and $71,725 for children with other coverage. This calculation assumed that (1) average income was at the midpoint of each income category and at 450% of Federal Poverty Level (FPL) for children in the 400%+ category and (2) uninsured children were spread proportionally across non-Medicaid children in the income categories up to 400% of FPL. Weighting income by coverage with number of children by coverage times odds of AHT by coverage yielded an estimate that household income of AHT victims averaged $28,825 or 58.3% of national median household income (DeNavas-Walt et al. 2011). We assumed that estimate applied to individual income.

We assumed that in the absence of AHT, child income would have mirrored parental income. That is a lower bound estimate because Mitnik and Grusky (2015), using longitudinal tax return data, estimate that only half of low-income children are locked in poverty. We assumed that income of post-injury caregivers and perpetrators will equal parental income. In reality, other people—e.g., friends, grandparents, babysitters, or foster parents—may fill these roles. We assumed the quantity/value of lost household work (15.5% of national median work loss for adults and 23.2% of lifetime earnings for young children) would not vary with income. That assumption is conservative since lower-income people are more likely than higher-income people to do household work themselves rather than hiring someone to do it.

We adjusted the costs of *perpetrator work loss if incarcerated* from a previous study (Miller and Hendrie 2014) to the parental earning level. We further reduced sanctioning-related costs downward by 25% from the average for homicide based on a study which reported that, controlling for felony class, sentences for child abuse deaths were 25% shorter than sentences for other homicides (Augé and Mitchell 2012).

DALYs, a standard measure of burden of disease, are computed by summing the discounted present value of life years lost by those who die prematurely plus years lived with disability by survivors (i.e., the portion of quality of life lost during those years) (Bourgeois et al. 2014; Murray et al. 2013). We applied published DALY estimates for AHT, as measured by the Health Utilities Index—Mark 2 (Drummond et al. 2007), based on a survey of AHT caregivers and pediatricians familiar with AHT ($n = 170$) (Miller et al. 2014). Our cost estimates started from a published dollar value of $180,407 per DALY, which excludes associated work loss, and an average discounted present value of 29.85 life years lost per fatal AHT, which equates to a value of $6.6 million (95% CI $2.3–$9.8 million) per child homicide inclusive of work loss (Blincoe et al. 2014; Cohen and Miller 2003; Miller and Hendrie 2014). We adjusted the value of a DALY to reflect the expected below-average lifetime income of AHT victims had they not been victimized. Specifically, we adjusted the estimates using an income elasticity of 0.47 from Viscusi and Aldy (2003), as recommended by Hammitt and Robinson (2011). Following guidelines from the Second Panel on Cost-Effectiveness in Health and Medicine (Neumann et al. 2016), we showed work and DALY losses separately.

To compute the present value of AHT costs per each US live birth, we used national distributions of age at AHT occurrence (Parks et al. 2012; Xiang et al. 2013). We used contemporaneous 2010 Vital Statistics data indicating 3,999,386 annual live births.

Standard Error of Estimates and Sensitivity Analysis

We used the Crystal Ball® add-in to Excel to simulate standard errors for the incidence and cost estimates (see Supplemental Table 1, available online). Crystal Ball® used Monte Carlo simulation techniques to run 100,000 estimates of the costs, drawing on estimated statistical distributions for each incidence and cost factor as inputs. The software determined the 95% confidence interval from the distribution of the 100,000 estimates. Importantly, because uncertainty around best estimates of some costs was asymmetric, simulated 95% confidence intervals around those estimates are unbalanced.

Additional sensitivity analyses assessed how total costs varied with factors that required a non-probabilistic analytic choice: (1) at discount rates of 2 and 4% (±1% from the reference case estimate of 3%) and of 7% (the rate the US Office of Management and Budget (1992) has prescribed for use in regulatory analyses for decades); (2) if the AHT severity distribution matched the distribution for all intentional brain injuries including AHT, assaults, and suicide acts for children aged 0–18 (Rivara et al. 2011) or matched the distribution in the survey by Miller et al. (2014); (3) if we used the 0.595 ratio of non-admitted to admitted hospital cases from the 2006–2009 HCUP Nationwide Emergency Department Database (which provides an undercount because some participating states did not code injury causes for patients who were treated and released) instead of the Marketscan-based rate of 0.684; (4) if annual medical costs for mild cases lasted only through age 4 (the age when the available data ended) or throughout the child's life span rather than the pediatrician's best estimate of age 18; and (5) if we income-adjusted published estimates of public willingness to pay to prevent a homicide of $5.8 million (Kochi and Taylor 2011), $13.0 million (Cohen et al. 2004), or $15.0 million (Corso et al. 2011) rather than $6.6 million.

Supplemental Estimates from a Government Perspective

Government typically pays special education, child protective services, and criminal justice costs. The 2009 KID data on expected payers (i.e., private insurance or public payers such as Medicare and Medicaid) for hospital inpatient care of AHT indicated that government sources paid 80% of associated medical costs. Foregone taxes average 14.5% of wage losses (work losses minus fringe benefits and household work) (Miller et al. 2011). We applied this rate of foregone taxes to the work loss costs estimated for caregivers and victims, as well as for perpetrators while incarcerated, to estimate the amount of lost tax revenue.

AHT Prevention Programs

AHT prevention programs have been evaluated in pre-post effectiveness trials (Barr, Barr et al. 2009; Barr, Rivara et al. 2009; Dias et al. 2005; Dias et al. 2017; Fujiwara et al. 2012; Keenan and Leventhal 2010; Zolotor et al. 2015). We estimated the effectiveness required for these programs to break even by combining our cost estimates with existing data on program costs and effectiveness. Delivering one hospital-based program costs $5 per family educated in 2010 dollars (Altman et al. 2011; Dias et al. 2005). Similarly, delivering the *Period of PURPLE Crying* program in a hospital maternity ward costs an estimated $4 per family educated (Pointer 2011). The literature does not document any more intensive

interventions that target shaking-related AHT. We used a $5 cost per family to avoid understating the cost of prevention.

It is unclear if the existing programs are effective. Pooling binomial outcome data from two pre-post evaluations of a hospital-based AHT prevention program (Altman et al. 2011; Dias et al. 2005), hospital-admitted AHT cases per 100,000 babies declined from 25.9 to 13.6 (a 47.7% reduction, 95% CI 15.6–67.5) following the program. Rates changed minimally in neighboring states without the programs. Conversely, the AHT rates in North Carolina and Pennsylvania did not fall after large-scale program implementation (Shanahan et al. 2013; Zolotor et al. 2015; Dias et al. 2017), and an educational video shown in Utah had no effect (Keenan and Leventhal 2010). Given these mixed-to-negative results, we chose to compute the break-even effectiveness for a program but not to make a best effectiveness estimate and compute a benefit-cost ratio. That calculation excluded the savings in victim work loss and quality of life.

Results

In 2010, Miller et al. (2014) estimated AHT killed 334 abused children, with another 4490 injured including 1962 severe cases, 1163 moderate cases, and 1365 mild cases. From a societal perspective, the discounted lifetime average cost of each AHT death and surviving AHT victim were $5.7 million (95% CI $3.2–9.2 million) and $2.6 million (95% CI $1.0–2.9 million), respectively (Table 2). Subtracting the cost of lost work and decreased quality of life, estimated out-of-pocket costs were $544,000 per fatality (95% CI $481,000–594,000) and $224,000 per surviving AHT victim (95% CI $187,000–262,000). Table 2 reports estimated lifetime costs by more detailed categories and AHT severity.

The collective lifetime cost of AHT that occurred in 2010 was an estimated $13.5 billion (95% CI $5.5–16.2 billion), including $1.2 billion (95% CI $0.9–1.4 billion) in medical and other out-of-pocket costs (consisting of $257 million in medical costs, $552 million in special education costs, and $323 million in child protective services and criminal justice costs), $2.0 billion in work losses (95% CI $1.4–2.6 billion), and $10.3 billion in lost quality of life (95% CI $2.5–12.8 billion) (Table 3). Governments paid an estimated $1.3 billion of the total cost (95% CI $1.0–1.5 billion).

AHT costs an estimated $3300 per live birth in the USA (95% CI $1381–4045) including $284 in out-of-pocket costs (95% CI $238–356) (Table 4). This estimate is the present value at birth of expected lifetime AHT costs, accounting for the age distribution of abuse. Using a hospital-based prevention program that cost $5 would yield a net out-of-pocket cost saving for society and for government if it prevented at least 1.8% (5/284) of AHT cases.

Sensitivity Analyses

As detailed in Table 5 and in the “Methods” section, sensitivity analyses examined how total costs and costs paid by governments changed under alternate analytic choices and assumptions. Total cost estimates from the sensitivity analyses ranged from $7.9 billion to $32.1 billion, with costs paid by governments ranging from $0.9 billion to $1.5 billion. The largest uncertainty in the cost estimates related to the quality of life loss and its valuation.

Since government pays none of the quality of life costs, total costs were more sensitive to analytic choices than were costs paid by governments.

Discussion

AHT is very debilitating. An estimated one in 14 cases will be fatal before hospital discharge, and more than half of severely injured survivors will die before age 21. More than 40% of survivors are severely injured, with costs exceeding $3 million each. Even a mild case results in an average estimated loss of 15.5% of the child's health-related quality of life and costs over a million dollars.

Decomposing our non-fatal AHT medical cost estimate, costs averaged $34,750 per survivor in the first 3.5 years post-injury, similar to a New Zealand estimate of US$35,300 based on 44 cases, but the New Zealand estimate excluded physician's office cost (Friedman et al. 2012). (The online supplement details the New Zealand costs and their conversion to US dollars.) Our estimated lifetime special education costs averaged $123,000 per survivor, well above the New Zealand estimate of USD$39,100. Conversely, our estimated $39,700 per survivor in lifetime child protective and criminal justice services costs is well below the New Zealand estimate of USD$70,200. Most importantly, the New Zealand expenditures of USD $523,300 for adaptive equipment, home modifications, and attendant and home help care largely equate to unmet needs or unmeasured personal expenses in the US system.

This study's main limitation is its unavoidable reliance on published estimates from convenience samples, notably in the survey to determine DALY loss over time by AHT severity (Miller et al. 2014). Our cost estimates were informed by a previous AHT study that used MarketScan data, a large but non-representative sample of insurance claims (Peterson et al. 2014). It is unclear how well Marketscan identifies AHT cases. Marketscan identifies 1.46 live hospital inpatient discharges for AHT per case treated in the ED and released (or left against medical advice). By comparison, the HCUP National ED Sample identifies 1.68. A third limitation is the modest precision of our estimates of some small costs, notably costs related to perpetrators and adult mental health services. However, those costs represent less than 2% of total costs. We also relied on non-representative survey data from a recent publication, although that study included comparisons with the national incidence datasets used here that suggest the survey captured data about AHT victims who were demographically similar to the overall population of AHT victims (Miller et al. 2014).

Despite limitations, this study provides the first well-founded US estimate of lifetime costs associated with AHT. Total annual costs of AHT are high, about one fifth of the total annual costs associated with the more prevalent problem of underage drinking (Miller et al. 2006). The nation has invested in underage drinking prevention in virtually every school (Ringwalt et al. 2011) and alcohol sales outlet.

If existing prevention programs reduced AHT by as little as 2%, they would yield a net out-of-pocket saving. Perhaps because evidence for the effectiveness of these programs is mixed, sizable numbers of hospitals and pediatricians have not yet adopted them (National Center on Shaken Baby Syndrome (n.d.)). In the absence of more definitive evaluation, this study's

estimates provide limited guidance for future investment decisions. Better effectiveness estimates are needed for both broad prevention messaging and intensive prevention targeting high-risk caregivers. With only 1 in 825 live births resulting in AHT, mounting a well-controlled evaluation of intervention impact unavoidably will be difficult and expensive.

When a child survives AHT, providers and caregivers can anticipate a lifetime of potentially costly and life-threatening care needs. To our knowledge, this analysis provides the first comprehensive US estimates of the likely financial burden and its variation with AHT severity. Future research to refine the estimates might focus on (1) tracking impact on quality of life for a more representative sample of victims and (2) identifying and proactively tracking mild cases and latent ones that are not treated in hospital within 48 h of identification. Data about the number, circumstances, and outlook of the latent cases are especially tenuous.

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Table 1

Incidence and cost model components and their sources

Component	Data source and details/computations
Incidence	
Deaths in hospital	261 deaths; 2009 HCUP KID (Miller et al. 2014)
Deaths not in hospital	73 deaths; 2009 Vital Statistics mortality (Miller et al. 2014)
Hospital admissions	2211 cases; 2009 HCUP KID (Miller et al. 2014)
Emergency department treated and released	1515 cases; admissions times ratio of 0.338 treated and released/0.494 cases admitted from Peterson et al. (2014)
Cases not promptly medically treated	764 cases; admissions times ratio of 0.168 treated and released/0.494 cases admitted from Peterson et al. (2014)
Unit costs	For data values, see Table 2
Medical care cost for survivors	Peterson et al. (2014)
Medical care cost of fatalities	Original calculations using methods from Finkelstein et al. (2006)
Special education	Chambers et al. (2003)
Child protective, victim, adjudication, and sanctioning costs, mental health care costs of homicide, and perpetrator work losses while incarcerated	Miller and Hendrie (2014) with sanctioning costs adjusted downward by 25% based on Augé and Mitchell (2012) and further adjusted to average earnings of parents of AHT victims computed from Niederkrotenthaler et al. (2013)
Work loss due to death and injury	Lawrence et al. (2000) and Blincoe et al. (2014), adjusted to average earnings of parents of AHT victims
DALYs lost to non-fatal injury	Miller et al. (2014)
Dollar value of a DALY net of work loss	Miller and Hendrie (2014), adjusted to average earnings of parents of AHT victims using income elasticity from Viscusi and Aldy (2003)

Table 2

Cases, costs per case, and disability-adjusted life years per case of abusive head trauma by severity, USA, 2010

Cases	**Mild**	**Moderate**	**Severe**	**Non-fatal**	**Fatal**
	1,365	**1,163**	**1,962**	**4,490**	**334**
Medical care	50,500	72,695	48,374[a]	55,319	26,497
Special education	92,573	146,000	130,500	122,984	
Child protective services	37,018	37,018	37,018	37,018	
Victim services	21	21	21	21	
Police	80	80	80	80	2,273
Criminal justice	2,589	2,589	2,589	2,589	430,277
Perpetrator work loss while incarcerated	400	400	400	400	74,539
Adult mental health services		5,112	10,735	6,015	10,735
Lost work	3,339	118,386	815,205	387,931	815,205
Disability-adjusted life years ($)	689,808	792,206	3,530,746	1,957,861	4,377,575
Total	876,327	1,174,507	4,575,668	2,570,218	5,737,101
Disability-adjusted life years	4.7	5.4	24.1	13.3	29.9

In 2010 dollars, future costs converted to present value using a 3% discount rate

[a]Costs are lower for severe cases because these children have very short life spans

Table 3

Total costs and DALY burden due to abusive head trauma, USA, 2010

	Non-fatal	Fatal (within 30 days)	Total	95% CI for total	Percent
Medical care	248,382,000	8,850,000	257,232,000	201,642,000–313,576,000	1.9%
Special education	552,198,000	0	552,198,000	365,574,000–739,200,000	4.1%
Child protective services	166,211,000	0	166,211,000	135,889,000–196,569,000	1.2%
Victim services	94,000	0	94,000	75,500–113,000	0.0%
Police	359,000	759,000	1,118,000	932,000–1,305,000	0.0%
Criminal justice	11,625,000	143,713,000	155,338,000	132,084,000–178,582,000	1.2%
Perpetrator work loss	1,796,000	24,896,000	26,692,000	14,600,000–34,173,000	0.2%
Adult mental health services	27,007,000	3,585,000	30,592,000	23,632,000–37,557,000	0.2%
Lost work	1,741,810,000	272,278,000	2,014,088,000	1,423,036,000–2,605,910,000	15.0%
Disability-adjusted life years ($)	8,790,796,000	1,462,110,000	10,252,906,000	2,457,687,000–12,840,720,000	76.2%
Total	11,540,278,000	1,916,192,000	13,456,470,000	5,523,934,000–16,978,924,000	100.0%
Disability-adjusted life years	59,953	9,972	69,925	50,376–92,167	
Cases	4,490	334	4,824	4,087–5,561	

In 2010 dollars, future costs converted to present value using a 3% discount rate

Table 4

Costs per live birth due to abusive head trauma and estimated savings per child from hospital-based prevention, USA, 2010

Cost category	Per birth ($)
Medical care	63
Special education	135
Child protective services	41
Victim services	0.02
Police	0.27
Criminal justice	38
Perpetrator work loss	7
Adult mental health services	7
Lost work	492
Disability-adjusted life years	2504
Total	3287
Out-of-pocket costs	291
Costs paid by government	312
Quality-adjusted life years lost	.017

In 2010 dollars, present value computed at a 3% discount rate, accounting for distribution of age at abuse and timing of costs after abuse occurs

Table 5

Sensitivity analysis showing the effects of assumptions and modeling choices on total costs of AHT and costs paid by government

Change in model	Total cost (billions)[a]	Costs paid by government (billions)[a]
Best model estimates	13.5	1.3
2% discount rate	15.0	1.5
4% discount rate	12.5	1.1
7% discount rate	11.0	0.9
Severity distribution for intentional brain injuries	7.9	1.1
Severity distribution from survey	17.8	1.4
Non-admitted cases from NEDS	9.1	0.9
Medical costs for mild cases only through age 4	13.4	1.3
Medical costs for mild cases throughout life span	13.5	1.3
Willingness to pay to prevent a homicide of $5.8 million	12.8	1.3
Willingness to pay to prevent a homicide of $13.0 million	27.9	1.3
Willingness to pay to prevent a homicide of $15.0 million	32.1	1.3

[a]2010 USD