# A Probabilistic Analysis of Short Fall Arguments in Legal Cases of Abusive Head Trauma

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**Abstract**

The diagnosis for Abusive Head Trauma (AHT), a type of brain injury in infants, is made by carefully excluding other possible causes of the symptoms that can mimic the symptoms of AHT. For instance, in cases in which the defendant claims that an accidental short fall and not shaking or abuse has caused the head trauma, a quantity from Chadwick et al. (2008) is used to exclude a short fall as the cause of the injuries. In court, the following argument has been made numerous times: Since the probability that a child will die from a short fall is so small, it must be that the probability the child died from shaking is very high. So, the defendant is guilty of child abuse and/or murder (e.g. see People vs. Bailey (2014), State of Florida vs. Kareem Daniel Farrell (2013), Cathy Lynn Henderson Hearing (2009), State of Florida Vs. Ramgoolie (2014), and State of Wisconsin vs. Patrick L. Donley (2014)). First, I argue that although Chadwick's quantity is correctly calculated, the way it is used in court is incorrect. Second, I propose a quantity to help answer the question, "Could this child's injuries have been caused by a short fall?" Third, I argue that a dataset with the characteristics needed to calculate this quantity is not available today. Hence, no quantity can be properly calculated with the information that is currently available, and the argument, as it is used today, should not be used to exclude a short fall as the cause of an infant's injuries.

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# 1 Introduction

When a child is diagnosed with head trauma, legal investigations are often carried out to determine whether the case involved child abuse, specifically, Abusive Head Trauma or AHT (previously known as Shaken Baby Syndrome or SBS). According to the US Centers for Disease Control and Prevention, AHT is "an injury to the skull or intracranial contents of an infant or young child (less than 5 years of age) due to inflicted blunt impact and/or violent shaking" (Parks et al., 2012). The CDC says that the AHT diagnosis is made by carefully excluding other possible causes of the symptoms that can mimic the symptoms of AHT. Selecting the correct diagnosis might appear like a well-defined and straightforward procedure, but it can be difficult to perform in practice. For this reason, this medical diagnosis has undergone scrutiny in recent years, and some legal cases have been overturned.

Short falls are one of the causes that some physicians argue (Moran et al., 2012) might mimic the symptoms of AHT. In the past decade, there have been numerous AHT cases in the United States (Medill Justice Project, 2015) in which the defendant has argued that the impact from a short fall, not shaking, caused the child's trauma and consequently death, and therefore that the cause of death was accidental. In some of these cases, Chadwick et al.'s 2008 paper is invoked, which states that the annual risk of death resulting from short falls among young children is 0.48 deaths per million.

Plunkett (2001) and Moran et al. (2012) also study short fall deaths, but they do not provide other values for the risk of death due to short falls in children. Plunkett (2001) lists 13 cases of children who had a short fall and died from the injuries, but does not provide an estimate of prevalence of deaths due to short falls. Moran et al. (2012) argue that Chadwick et al.'s quantity is calculated improperly because the database it uses is biased (in the sense that cases categorized as a death due to a short fall might be listed as death due to shaking), among other reasons, and thus the correct quantity is likely higher than 0.48 in a million.

Chadwick et al.'s paper is valuable in analyzing cases in which the defendant claimed that a short fall caused the brain injuries because no other paper estimates the prevalence of deaths due to short falls in infants, as far as the author of this paper is aware. In addition, Chadwick et al. provide specific definitions of short falls, which helps define the scope of the problem and makes the estimate more transparent. The authors' calculation of the prevalence of short fall deaths in infants is also clearly shown in the paper.

## 2 How is Chadwick et al.'s quantity calculated?

Chadwick et al. selected data from an injury database compiled by the State of California Department of Health Services called the California Injury Data Online and provided by the Epidemiology and Prevention for Injury Control Branch (EPIC) for the years 1999–2003 to create an estimate of the mortality rate due to short falls.[4]

The EPIC database contains information from discharges and death certificates submitted by all California hospitals and county medical examiners, respectively. The authors selected the short-fall deaths by selecting the 20 fall death subcategories (denoted by ICD-10 codes) and separating them into groups called "short fall", "long fall", and "not applicable".

The authors selected the relevant cases to include in their analysis by determining which types of falls recorded in the data counted as short falls. They included the following as "short falls" in their analysis: fall on same level involving ice and snow, fall on same level from slipping, tripping, and stumbling, other fall on same level attributable to collision with, or pushing by, another person, fall while being carried, fall involving wheelchair, fall involving bed, fall involving chair, fall involving other furniture, and fall on and from stairs and steps. They excluded the following because they considered them to be "long falls": fall on and from ladder, fall on and from scaffolding, fall from, out of, or through building or structure, fall from tree, fall from cliff, and Other fall from one level to another. They excluded the following because they considered them "not applicable": fall involving ice skates, skis, roller skates, or skateboards, fall involving playground equipment, diving or jumping into water causing injury, and unspecified fall.

Chadwick et al. found that there were at most 13 short-fall deaths in the population of 2.5 million California children who were less than 5 years of age. Seven of the 13 cases were dismissed due to coincidence of suffocation, falling from a two-story window that was too high for the criterion of "short fall", falling from an undetermined height, falling onto rocks in the arms of an adult, and crush injuries from heavy furniture falling. The six remaining cases were considered possibly valid short-fall deaths, which yielded the calculation,

$$\frac{\text{Number of infants who have died from a short fall in a specific year}}{\text{Number of all infants in that year}}$$
$$= \frac{\text{6 cases/2.5 million children}}{\text{5 years}} = \frac{\text{0.48 cases/1 million children}}{\text{year}}. \tag{1}$$

[4]Today, the data can be found online at `http://epicenter.cdph.ca.gov/ReportMenus/InjuryDataByTopic.aspx`. Last accessed on October 20, 2015.

This can be written in terms of probabilities as

$$P(\text{ Child had a short fall and died in a specific year} \mid \text{Individual is an infant in that year}). \tag{2}$$

Chadwick et al. also noted that since some of the short fall histories in the set were "incorrect", the true incidence of short-fall deaths is likely less than 0.48 cases per 1 million children.

I repeated the analysis by Chadwick et al. by using the updated EPIC database from 1999–2013, which now has 25 cases (there have been 12 cases in the 2004–2013 period in addition to the 13 cases from 1999–2003). Chadwick et al.'s procedure yields:

$$\frac{25 \text{ cases}/2.5 \text{ million children}}{14 \text{ years}} = \frac{0.71 \text{ cases}/1 \text{ million children}}{\text{year}}. \tag{3}$$

This shows that, indeed, the fatality codes for short falls are used very rarely in infants.

Chadwick et al. also reviewed other sources to check whether they could be used to calculate an estimate of the incidence of death from short falls, including the Consumer Product Safety Commission Data, five studies of "multiply and reliably witnessed falls", 25 studies of child care-related injuries, 12 studies using biomechanical analyses, over 50 studies of large clinical populations, seven studies comparing abusive and unintentional injuries, and others.

In addition to using the EPIC data, the authors proposed another analysis, by using the Consumer Product Safety Commission Data, called the National Electronic Injury Surveillance System (NEISS), to provide another measure of incidence, which is that 0.625 cases per 1 million young children per year die from short falls. However, the authors say that these data might not be "sufficiently reliable" for the purposes of estimating the incidence because they do not include information about violence leading to the falls and due to the nature of the data they may miss deaths resulting from short falls that are not involved with products.

Chadwick et al. finally settle on the quantity of 0.48 as an upper bound of the number of short-fall deaths in children 0–5 years of age in one year.[5] According to my analysis, this calculation is correct and agrees with the EPIC data that is publicly available. However, the way in which this quantity is used in court is flawed.

[5]Chadwick et al.'s quantity is specific to the state of California, for which the data were readily available. They do not address the question of how his quantity might translate to the entire United States, or to other individual states. But that is out of the scope of this paper.

# 3 How is Chadwick et al.'s quantity used in court?

The US court system is adversarial, which implies that the question of what happened to a specific child reduces to asking whether the child was abused (i.e. shaken in cases of AHT) or had an accidental short fall.

Prosecutors have used Chadwick's quantity to make the argument that since the probability that a child will die from a short fall is so low (0.48 in 1 million), it must be that the probability the child died from shaking is very high. Therefore, the defendant is guilty of child abuse and possibly murder depending on whether the child is alive. This argument has been made numerous times in court (see People vs. Bailey (2014), State of Florida vs. Kareem Daniel Farrell (2013), Cathy Lynn Henderson Hearing (2009), State of Florida Vs. Ramgoolie (2014), and State of Wisconsin vs. Patrick L. Donley (2014)).

In terms of probability, the implicit claim used in court is that

$$0.48 \text{ in a million} = P(\text{ Child had a short fall} \mid \text{Evidence }). \tag{4}$$

where the evidence is that the infant had head trauma and died. In cases in which the child is still alive, then the evidence is that the child had head trauma.

Assuming that 0.48 in a million = $P$( Child had a short fall | Evidence ) implies that

$$P(\text{ Shaken} \mid \text{Evidence }) = 1 - 0.48 \text{ in a million } = 99.9999\%. \tag{5}$$

The argument "short falls almost never cause deaths, therefore the defendant must have abused the child," is flawed for the reasons listed in the next section.

# 4 Criticisms of the implicit argument made in court by using Chadwick et al.'s quantity

Determining whether a specific child with head trauma (who might have died or might still be alive) is a difficult task, so it makes sense to use the only quantity available for the prevalence of short fall deaths in infants. However, I argue that the question, "Could this child's injuries have been caused by a short fall?" should not be answered by using Chadwick et al.'s quantity for three reasons.

### 4.1 Reason 1: Rare events are not impossible

While it is true that children rarely die from a short fall, it is false that children cannot die from a short fall. There are approximately 24 million infants in the United States today according to the CDC (Martin et al., 2012), which implies that if 0.48 out of 1 million children die from a shot fall in a year we would expect to see 12 children die from a short fall this year alone. It is possible that the child in a specific case could be one of these 12, so merely citing the rarity of an event does not mean it is impossible.

This argument has been mentioned by several expert witnesses in court (see People vs. Bailey (2014)) as well as by Moran et al. (2012).

### 4.2 Reason 2: One must restrict the population in light of the evidence to a subset of individuals

Chadwick et al.'s quantity is calculated for the entire population of infants of the state of California. But we have additional information in each case. We not only know that the individual is an infant, but we in fact know that the infant had a head trauma and died (or did not die, for the cases in which the child is still alive). In terms of probability statements, the probability that the child had a short fall given the evidence (i.e. that the infant had head trauma and died) can be written as

$$P(\text{ Short fall} \mid \text{Evidence }), \tag{6}$$

where the evidence is that the infant has a head trauma and died. When one restricts the analysis in light of the evidence to the population of infants with head trauma and death (see Figure 1) the population of interest is greatly reduced. The reason it is greatly reduced is because the event of an infant having head trauma and death is rare, which can be seen by performing a similar analysis to that in Chadwick et al. A similar argument has been mentioned by Moran et al. (2012).

### 4.3 Reason 3: One must compare competing hypotheses in light of the evidence

Chadwick et al.'s quantity is calculated in isolation. That is, the authors calculate the probability of one event, but they do not calculate the probabilities of any other possible causes for comparison, and this is problematic in using the quantity in court. The value of 0.48 in 1 million seems small, and indeed research in psychology has shown that quantities

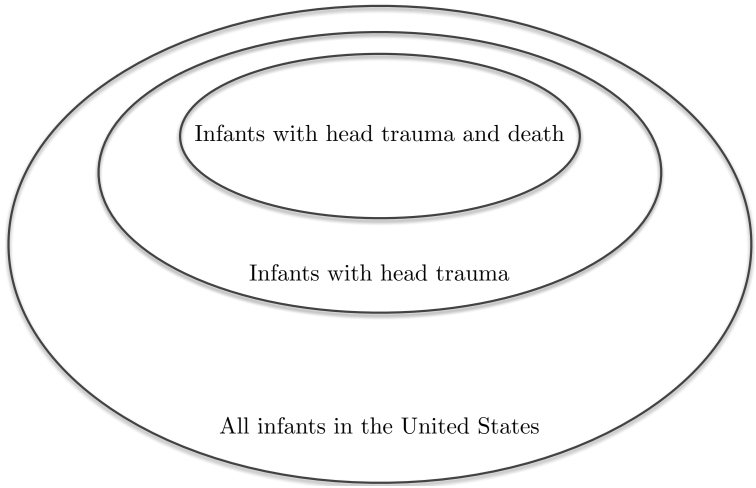


Figure 1: Subsets of the population. One must restrict the analysis to the population of interest, namely, the infants who have a head trauma, have died, and have a history of a short fall, which is a much smaller population than the entire population of infants in the US.

such as "1 in a million" is a sort of magic number that feels very small to a jury, regardless of how it compares to other values (see Thompson et al. (2003) and Thompson et al. (2013)). However, when compared to the probabilities of other possible events (e.g. any other cause that might mimic the symptoms of AHT), it is possible that 0.48 in a million is no longer small but very large. In order to compare the probabilities of competing hypotheses one should calculate the comparative quantity:

$$\frac{P(\text{ Short fall } \mid \text{ Evidence })}{P(\text{ No short fall } \mid \text{ Evidence })}, \tag{7}$$

where the evidence is, as earlier, that the child had a head trauma and death.

But there could be other possible causes for the child's injuries. For example, a lack of vitamin D, rickets, and some gastrointestinal disorders can mimic the symptoms of AHT (Moran et al., 2012). Therefore, ultimately we would like to know whether it is more likely that the child was shaken versus that the child was not shaken, as this would compare the probability that the child was abused versus any other option. This can be calculated with the following more appropriate quantity, which compares competing hypotheses in light of the evidence:

$$\frac{P(\text{ Shaken } \mid \text{ Evidence })}{P(\text{ Not shaken } \mid \text{ Evidence })}. \tag{8}$$

To see how the "short fall" piece fits into the calculation, we could split the denominator up into the cause that the child had a short fall and other causes (note that Equations 8 and

9 are equivalent):

$$\frac{P(\text{ Shaken } | \text{ Evidence })}{P(\text{ Short fall } | \text{ Evidence }) + P(\text{ Other causes } | \text{ Evidence })}. \tag{9}$$

The value of Eq. 8 would determine whether it was more likely that this child was shaken, which could lead to the jury deciding that the defendant is guilty, versus that this child had an accident. But, as I will show in the next section, this quantity is difficult to calculate.

# 5 Obtaining a value for the more appropriate quantity, Eq. 8

Estimating the value of the quantity cited in Equation 8 is difficult because the statistician can estimate only part of the quantity, and in order to estimate the quantity the statistician needs certain values for which there are no adequate datasets available today. I expand on these reasons in the next two sections.

## 5.1 Obstacle 1: The statistician can only estimate part of the quantity in Eq. 8

The first obstacle in calculating the quantity in Equation 8 is that the statistician can only estimate the part of the value that relies on data. The quantity can be divided into a product of two quantities by using Bayes rule:

$$\frac{P(\text{ Shaken } | \text{ Evidence })}{P(\text{ Not shaken } | \text{ Evidence })} = \underbrace{\frac{P(\text{ E } | \text{ Shaken })}{P(\text{ E } | \text{ Not shaken })}}_{\text{From data}} \underbrace{\frac{P(\text{ Shaken })}{P(\text{ Not shaken })}}_{\text{From case}}. \tag{10}$$

The first factor can be estimated by a statistician by using a reliable data source. The second factor (a factor of marginals) will be specific to each case and it will depend on additional evidence (e.g. whether the adult spent much time with the child, or whether the child had injuries from prior abuse), the opinion of the jury, and the opinion of the judge.

So, by using a statistical analysis we can only arrive at the value marked as “From data” in Equation 10 and this should be weighted by the additional information from the specific case in order to take a first step in determining the value of Equation 8.

If we want to separate the individuals who had short falls, as in Equation 9, we can rewrite this using Bayes rule as follows:

$$\frac{P(\text{ Evidence } | \text{ Shaken })P(\text{ Shaken })}{P(\text{ Evidence } | \text{ Short fall })P(\text{ Short fall }) + P(\text{ Evidence } | \text{ Other causes })P(\text{ Other causes })}, \tag{11}$$

where we have cancelled out the division of each term by $P(\text{ Evidence })$. In this case, the statistician can only estimate the following quantities:

- $P(\text{ Evidence } | \text{ Shaken })$
- $P(\text{ Evidence } | \text{ Short fall })$
- $P(\text{ Evidence } | \text{ Other causes })$

and the marginals, $P(\text{ Shaken }), P(\text{ Short fall })$, and $P(\text{ Other causes })$ will depend on additional evidence that is specific to each case.

## 5.2 Obstacle 2: To estimate the quantity in Eq. 8 one needs values that are not currently available

The second obstacle is related to problems with the data. To evaluate the quantities, let the evidence be defined as "head trauma". We can change the definition of the evidence, (for example, to a combination of medical features, such as retinal hemorrhages, cerebral hemorrhage, and subdural hematoma, or in the cases in which the child has died, we can change it to be "head trauma and death") depending on which symptoms are considered to be common among the AHT cases. Selecting the common symptoms is a task better suited for physicians and child abuse specialists, but for the sake of argument we do this analysis letting the evidence be the child's "head trauma".

We said in the last section that the statistician can estimate the quantity found in the right hand side of Equation 10. In the ratio labeled as "From data", if we replace "Evidence" with "Head trauma" we get:

$$\frac{P(\text{ Head trauma } | \text{ Shaken })}{P(\text{ Head trauma } | \text{ Not shaken })}. \tag{12}$$

To estimate this quantity, we need to be able to fill in the values for $c_{11}$ and $c_{12}$ in Table 1.

| | Shaken | Not shaken |
|---|---|---|
| Head trauma | $c_{11}$ | $c_{12}$ |

Table 1: Table of frequencies required to estimate the probabilities in Equation 12.

To find the values of $c_{11}, c_{12}$, one might be tempted to use a major database, such as EPIC and KID (these will be described later), by selecting the cases of infants who were shaken and have head trauma, and those who were not shaken and have head trauma. A number could be obtained by using a simple calculation.

However, some major databases, such as EPIC and KID, are insufficient for finding the values in Table 1. The EPIC database, which Chadwick et al. used to estimate their quantity of 0.48 in a million, has a small sample size, as it is limited to the population of California and the events required for the analysis are too rare. In addition, the California population is not representative of the United States population.

The KID database[6] is produced by the Healthcare Cost and Utilization Project (HCUP), a Federal-State-Industry partnership sponsored by the Agency for Healthcare Research and Quality (AHRQ) of the US Department of Health & Human Services. It provides information about nearly 1.7 million hospital admissions among children aged 0-5 years. It contains dispatch information, including records of primary and secondary diagnoses in ICD-9 code format, whether the child died, and external events (including short fall). The KID database only contains information from hospital records.

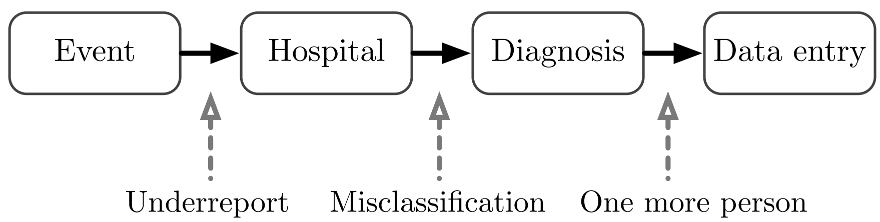


Figure 2: Possible scenario that follows an event in which a child gets a head injury. The event could be a short fall and/or head injury, then the child is taken to the hospital, he receives a diagnosis from a physician, and finally, the data about the diagnosis is entered into a system. Several problems, such as underreporting, misclassification, and data entry errors could introduce bias to the data.

Additionally, both the EPIC and the KID databases are biased by several factors. Figure 2 shows a possible scenario: Once a child has an event in which he falls and/or gets a head injury, the adult might not take him to the hospital. This results in underreporting of head injuries and/or short falls. At the hospital, it is possible that a physician misclassifies the case as a short fall when it was shaking, or vice versa. This results in a misclassified diagnosis. Lastly, the child's diagnosis should be entered in a database, and it is possible that the individual responsible for entering the data does not do so, or the diagnosis is changed and the data is not, or the individual decides to enter the wrong code for cases like these consistently. Many other scenarios could lead to biases in the data.

[6]The KID database can be found online at: `https://www.hcup-us.ahrq.gov/kidoverview.jsp`. Last accessed: December 13, 2015.

For instance, the number of infants who have had a short fall and have no head trauma is greatly underreported, since children often fall at home from low heights and are unharmed, so the caretakers do not take them to the hospital nor report it so it ends up in a database. A similar argument holds for a baby that was shaken and had no symptoms. Also, since the diagnosis of Abusive Head Trauma has been so hotly debated recently, it is possible that some physicians diagnose a case as shaken and other diagnose the same case as a short fall or another cause.

So, the data themselves are the problem, and for this reason, one cannot reliably calculate the quantity from Equation 8.

# 6 Conclusion

Chadwick et al. (2008) produced the only numerical estimate for the rate of death from short falls in young children, which has been used in court cases because it provides a standard for how rare it is for a child to die from a short fall. However, this quantity is used improperly in court. In several cases, prosecutors have argued that since the probability that a child will die from a short fall is so low, it must be that the probability the child died from shaking is very high. Therefore, the defendant is guilty of child abuse and possibly murder. This argument is flawed for three reasons.

I argue, first, that rare events are not impossible, so saying that death in children due to short falls is rare is not informative, without other evidence, when deciding whether a specific child died from a short fall. Second, Chadwick's quantity is calculated for the entire population of infants, but we have additional information, not just that this is an infant. So, one must restrict the population in light of the evidence to a subset of individuals. Third, Chadwick et al.'s quantity is calculated in isolation. They calculate the probability that one event happens, but not the probabilities that any other possible cause happened for comparison. There is no information about how likely the other possible causes are. So, one must compare competing hypotheses in light of the evidence.

In order to improve these three points in legal arguments, one should calculate a different quantity, namely the probability that the child was shaken given the evidence, divided by the probability that the child was not shaken given the evidence. The data required to calculate this ratio reliably is biased in datasets due to possible misclassification. In addition, the data need to be representative of the population.

To the best of our knowledge, a dataset with these characteristics is not currently available. Hence, a quantity that answers the question, "Could this child's injuries have been caused by a short fall?" cannot be properly calculated with the information that is available today.

In future work, it would be interesting to answer the question, What data could be gathered so the quantity could be calculated? One possibility is a longitudinal survey that tracks a randomly selected group of infants over the first five years of life (five because AHT tends to occur before age five). The survey could ensure the infants are checked for head trauma regularly, and it could ask parents to report every time they are aware of their child being shaken, falling, and whatever other activities might be suspected to cause head trauma (this would fall under the "other causes" category). This could potentially help policy makers and health officials decide which surveys and data collection efforts to fund in order for researchers to estimate quantities based on reliable evidence and thus, to provide information that makes the court system more fair in cases of child abuse and Abusive Head Trauma.

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