SPECIAL ARTICLE

Drug Safety 2008; 31 (8): 637-642
0114-5916/08/0008-0637/$48.00/0

Is the Principle of a Stable Heinrich Ratio a Myth?

A Multimethod Analysis

Steve Gallivan,[1] *Katja Taxis*,[2] *Bryony Dean Franklin*[3,4] and *Nick Barber*[3,4]

1 Clinical Operational Research Unit, Department of Mathematics, University College London, London, UK
2 Department of Pharmacy, Division of Pharmacotherapy and Pharmaceutical Care (GUIDE), University of Groningen, Groningen, the Netherlands
3 Centre for Patient Safety and Service Quality, Imperial College Healthcare NHS Trust, London, UK
4 Department of Practice and Policy, School of Pharmacy, University of London, London, UK

Abstract

Background: Safety improvements are sometimes based on the premise that introducing measures to combat minor or no-harm incidents proportionately reduces the incidence of major incidents involving harm. This is in line with the principle of the Heinrich ratio, which asserts that there is a relatively fixed ratio between the incidence of no-harm incidents, minor incidents and major incidents. This principle has been advocated as a means of targeting and evaluating new safety initiatives.
Research Methodology: Both thought experimentation and analysis of empirical data were used to examine the plausibility of this principle. A descriptive statistical analysis was carried out using triangle plots to display the relative frequencies of the occurrence of safety incidents classified as minor, moderate or severe.
Findings: Thought experiments indicated that the principle of a fixed Heinrich ratio has a dubious logical foundation. Analysis of emergency department attendance and studies of medication errors demonstrated marked variation in the relative ratios of different outcomes. Triangle plots of UK road traffic accident data revealed a hitherto unrecognized systematic pattern of change that contradicts the principle of the Heinrich ratio.
Interpretation: This study of the principle of a fixed Heinrich ratio invalidates it: introducing measures to reduce the incidence of minor incidents will not inevitably reduce the incidence of major incidents *pro rata*. Any safety policies based on the assumption that the Heinrich ratio is true need to be rethought.

1. Background

Patient safety research is concerned with finding means for avoiding accidental and unplanned events (incidents) that either cause harm or have the potential to do so. A fundamental tenet of some safety research is that measures taken to reduce the incidence of 'no harm' or 'near miss' incidents inevitably reduce the number of major incidents in which patients are harmed. This was a view originally championed by a safety expert, Herbert W. Heinrich,[1] whose work gave rise to the principle of the Heinrich ratio. Studying insurance claims forms for industrial accidents in the 1920s, Heinrich developed a three-way categorization of incidents, depending on their outcome. He classified them as 'no-injury accidents', 'minor injuries' and 'major injuries', and suggested that the relative frequency of these events is comparatively constant. This gives a rationale for a belief held by some in safety science that reducing the incidence of minor or no-harm incidents will lead to a proportionate reduction in harm. It has been suggested that the Heinrich ratio can be used in quantitative terms and that the overall effects of new safety measures can be estimated by monitoring minor incidents and then inferring the reduction in major incidents by *pro rata* scaling.[2-4] Whilst much of the early work in this area has been carried out in industry, the principle of a fixed Heinrich ratio is increasingly referred to in the emerging field of patient safety research.[5-7]

Calculating a Heinrich ratio is simply a matter of deriving the relative ratios of three numbers. It is thus undoubtedly true that such ratios exist. This paper is more concerned with the scientific principle espoused by Heinrich that such ratios are constant.

Here, our aim is to establish whether the principle of a fixed Heinrich ratio is sound.

2. Research Methodology

Some may find our research methods unusual in that we use deductive, rather than inductive inference. Inductive inference is by far the most common form of investigation used in healthcare research. However, it is not the only valid scientific method. In deductive inference, the focus is on generating new knowledge by examining the logical consequences of a given set of facts.[8] There are many ways this might be done and the world of deductive science is nowhere near as formulaic as that of inductive science. Deduction, often using mathematics or formal logic, can take many forms. These include the use of the 'thought experiment' (Gedankenexperiment), which has a long tradition dating back to 1812, perhaps most notably in the work of Einstein. Note that it may only take one case to establish that a principle is unsound. For example, the statement, "All swans are white." can be refuted by the discovery of a single black swan.

Our research has been sequential, using a range of methods and approaches in a sequence of studies, each providing different grounds for refuting the principle of a fixed Heinrich ratio.

2.1 'Thought Experiments'

First, we explored the logic of the Heinrich ratio via thought experimentation, using deductive reasoning and mathematical modelling to fashion a series of vignettes to establish whether there were logical flaws in the notion of a fixed Heinrich ratio.

2.2 Empirical Data

2.2.1 Selection of Empiricial Data

We next reviewed the medical literature to find studies that reported numbers of incidents classified in three categories of harm. First, we examined a well documented example of medical harm, concerning outcomes for patients attending an accident and emergency department based on electronic case records of hospital discharges, emergency department records and death certificates.[9]

We then considered our own particular research area of medication errors. We conducted a literature review to find all original studies that reported the incidence of medication errors in the hospital setting by actual or potential outcome in at least three categories (minor, moderate and severe). The medication-error literature is particularly sensitive to methodological variation, so we only included studies that had sufficient detail regarding their methodology, including data collection methods and data analysis, to judge the quality of the study. Studies had to report the definition of the medication error, the exact method of data collection, a description of how the medication-error rate was calculated and a description of how the severity of the medication errors were determined. Studies were excluded if the results could not be recategorized. Studies were also excluded if data came from (spontaneous) incident reporting as this method is known to be associated with underreporting and possibly a bias towards reporting more serious errors.[10]

Finally, we searched for examples from outside the medical literature. We used data from road traffic accidents in Great Britain reported on an annual basis between 1993 and 2003.[11] Meticulous records are kept of every road traffic injury accident that is reported to the police. Great pains are taken to ensure that data are complete and a standardized data collection form is used, which provides little scope for non-uniformity in what is recorded in different centres.

2.2.2 Analysis of Empirical Data with a Triangle Plot

A graphical technique called the 'triangle plot' has been devised for displaying three relative proportions of the data from these studies as a point within an equilateral triangle. A point at the centre (technically the centroid) of the triangle corresponds to the case where the relative proportions are all equal. The further a point is from a vertex, the smaller the relative proportion is corresponding to the category associated with that vertex.

In principle, the results of several studies that categorize incidence into three severity categories can be displayed using a three-dimensional scatter plot, where the three coordinate axes correspond to the different severity categories and the results of a single study are represented by a point with coordinates that are the relative proportions of cases in each of the three categories.

This can be difficult to visualize. However, for each point, the three proportions sum to unity and, as a consequence, the scatter of points lies in a plane. Furthermore, since all the proportions are non-negative, a symmetry argument can be used to show that the scatter of points all lie on an equilateral triangle whose vertices correspond to the points where the plane meets three axes. These three points are at unit distance from origin. In view of this, subject to a certain amount of coordinate transformation, the scatter plot can equally well be represented as a two-dimensional scatter of points within an equilateral triangle. This is what we refer to as the triangle plot.

Standard methods exist for estimating confidence intervals for relative proportions when cases are assigned to one of two categories.[12] These have been extended so that within the triangle plot, an approximate 95% confidence region can be plotted, generally taking the form of a hexagon surrounding the point concerned.

2.3 Nomenclature

Medication errors and industrial accidents are incidents that take place in entirely different contexts. The harm associated with an industrial accident is usually apparent with harmful outcomes that can be observed. In medicine, however, one would classify many incidents as 'harmful', even though the patient might not perceive them as such, for example administering the wrong dose of a drug might reduce the clotting time of blood, but this would often not be noticed by the patient (although there are circumstances where there could be fatal consequences). In view of this, medication-error studies often rely on devising means for categorizing incidents in terms of the degree of potential harm. Even so, it is common to use a three-way classification of incidents. We shall refer to incidents as 'minor', 'moderate' or 'severe' in terms of the degree of harm or potential harm associated with them.

3. Findings

3.1 Thought Experiments

During the course of the study, thought experimentation was used to devise vignettes that illustrate the logical inconsistency of the notion of a fixed Heinrich ratio. Several were identified; the two most informative are summarized here.

3.1.1 Vignette 1

A version of Russian roulette is played with a revolver that has six chambers. One is loaded with a live cartridge, two are loaded with blank cartridges and the other three are left empty. The chambers are spun several times, the player places the gun against his head and pulls the trigger. Analysis of outcomes from this dangerous game show a remarkably consistent pattern. The relative frequencies of deaths, powder burn injuries and no injuries were in the ratio 1 : 2 : 3. In an effort to make the game safer (equivalent to a patient safety intervention), a new loading pattern was adopted with one live cartridge, one blank and four chambers left empty. This halved the proportion of powder burn injuries, but had no affect on the proportion of deaths, in contravention of a fixed Heinrich ratio.

3.1.2 Vignette 2

Consider a hypothetical study aiming to establish the proportion of newborn babies judged to be underweight. Using a continuous measure such as birth weight as a proxy for 'harm' allows us to address the

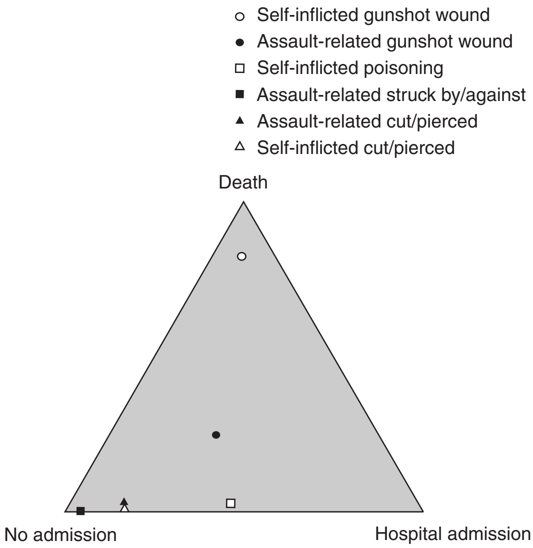

Fig. 1. A triangle plot illustrating the relative proportions of three different outcomes for patients attending an accident and emergency department. 'No admission' corresponds to patients treated within the unit.[9]

question of how one should determine what is abnormal. In the context of the Heinrich ratio, suppose that one wishes to categorize babies as 'normal', 'underweight' or 'grossly underweight'. Such a categorization relies on determining two threshold weights that define three weight bands. Clearly the ratio of numbers of babies assigned to each band relies on the choice of thresholds. Less obvious, but easy to establish mathematically, is that any set of relative ratios could be achieved by judicious choice of threshold values. Indeed, this does not depend on the distribution of weights being Gaussian, and it is sufficient that the cumulative probability distribution is continuous.

This shows that in cases where there is no natural three-way categorization of the harm associated with incidents, the rule chosen for stratification can have a major impact on the resulting Heinrich ratio. It does not support the notion that the ratio is constant.

3.2 Analysis of Empirical Data

The triangle plot shown in figure 1 summarizes the distribution of outcomes for accident and emergency department attendance, dependent on the type of accident. The closer a point is to a vertex of the triangle, the more frequent the corresponding outcome is in the data, starkly demonstrated by the point representing self-inflicted gunshot wounds that, unsurprisingly, are shown as having a high death toll. What is clear is that there is considerable heterogeneity of outcomes, which provides no support for a stable Heinrich ratio in this context.

Figure 2 summarizes the data from medication-error studies.[13-22] Again there is no support for a stable Heinrich ratio. The hexagonal 95% confidence regions for the grand mean of data shown in this plot did not overlap with those for any of the constituent datapoints shown. They are not shown since they clutter the diagram.

The triangle plot (figure 3) of road traffic data shows a tight cluster of points so, at first, seems suggestive that there might be some homeostatic mechanism at play. However examining the triangle plot more closely revealed a very systematic year-on-year evolution of the relative proportions of accident types, as shown in the expanded section of figure 3. The proportion of death accidents remains relatively constant. However there has been a steady shift to the left, whereby the proportion of serious accidents diminishes while the proportion of minor accidents increases. This is contrary to what would be expected if there were a constant Heinrich ratio;

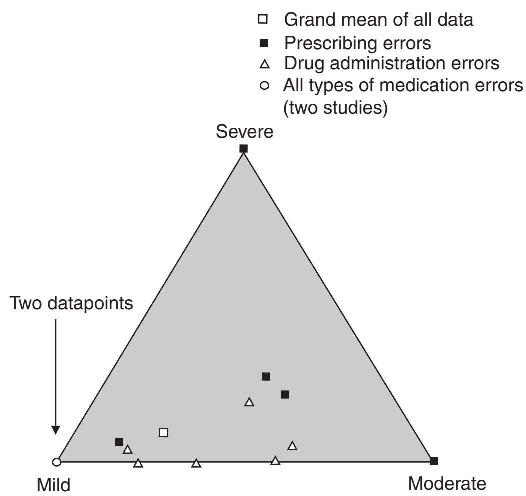

Fig. 2. A triangle plot showing the relative proportions of different severities of medication errors in 11 different studies.[13-22] Different symbols correspond to studies concerning different types of error.

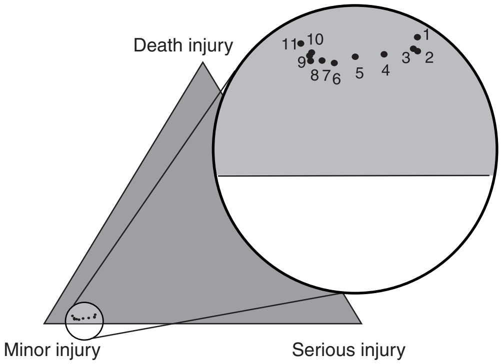

Fig. 3. A triangle plot showing relative proportions of road traffic accidents categorized according to their severity reported for Great Britain between 1993 and 2003.[11] Numbers indicate date order of plotted points.

indeed this exhibits the same behaviour as the Russian roulette thought experiment described above. Here, given the large sample size, 95% confidence regions are so small that they are comparable in size to the symbols used to represent the data.

4. Interpretation

At first sight, a potential criticism of our analysis of clinical incidents is that perhaps different studies use different criteria to categorize them in terms of outcomes. This may well be the case. However, this is akin to the problem identified in our second thought experiment (vignette 2). The Heinrich ratio is indeed likely to vary depending on the criteria used to categorize incidents, thus *de facto*, is not constant. In addition, the road safety data use well established and objectively defined criteria for the incidents and still do not support the Heinrich ratio.

There is currently considerable pressure to improve safety in relation to healthcare, and much needs to be done in terms of research.[23] One of the problems faced is that major incidents occur relatively infrequently and are thus difficult to study. On the other hand, minor incidents abound. In view of this, the notion of some form of fixed ratio between the two is appealing since, if this were the case, it would mean that the overall effects of new safety initiatives could be evaluated by focussing on minor incidents. Our work suggests that such reasoning is fallacious.

As we have shown, there may be circumstances in which remedial measures that reduce the frequency of minor incidents would have no effect whatsoever on the relative frequency of severe incidents; indeed it is not hard to imagine circumstances where the reverse might be the case. Introducing measures that reduce the incidence of minor surgical errors may, on the face of it, seem to be an admirable goal. However, an inadvertent effect might be that surgical trainees, having less exposure to what an experienced surgeon does when things go wrong, do not develop these skills themselves. Thus, later in the trainees' careers, when minor errors do occur, they might be much more likely to result in death.

It may be that the assumption of a fixed Heinrich ratio is reasonable in the patient safety field under special circumstances, in which the minor and severe errors both have the same cause. But the authors' experience is otherwise, and we have only found evidence of such 'common cause' analysis in one safety study related to the railway industry.[24]

Our findings also suggest that much of the effort spent on the analysis of data from minor incidents (e.g. as part of 'near miss reporting schemes') may be wasted, unless it can be established that minor incidents share a common cause with severe incidents. In our view, a substantial research initiative is needed to better understand the complex relationships between incidents and harm. If predictive relationships can be found, it will improve the choice of interventions and make their evaluation more feasible.

5. Conclusion

This paper raises serious doubts about the validity of assuming a constant Heinrich ratio linking the frequency of occurrence of safety incidents of different severities. It does not support the use of the Heinrich ratio as the basis of policy for the collection of safety data, for designing interventions or for evaluating them.

Acknowledgements

This work was funded by the Department of Health as part of its Patient Safety Research Programme. The study sponsor did not have any role in the study design; collection, analysis and interpretation of data; or the writing of the paper.

Contributions of authors: All authors were involved in designing the study and writing the final paper. Katja Taxis and Bryony Dean Franklin did most of the literature search; Steve Gallivan wrote the vignettes, developed the graphical method and did the data analysis; Nick Barber is the overall guarantor of the study. None of the authors have any conflicts of interest that are directly relevant to the content of this article.

References

1. Heinrich HW. Industrial accident prevention: a scientific approach. 1st ed. New York and London: McGraw-Hill Insurance Series, 1931
2. Bird FE, Germain GL. Practical loss control leadership. Rev. ed. Loganville (GA): Det Norske Veritas, 1996
3. Health and Safety Executive. The costs of accidents at work. Health and Safety Series booklet, HSG96 ed. London: Her Majesty's Stationery Office (HMSO), 1993
4. Phimister JR, Oktem U, Kleindorfer PR, et al. Near-miss incident management in the chemical process industry. Risk Anal 2003; 23 (3): 445-59
5. Bion JF, Heffner JE. Challenges in the care of the acutely ill. Lancet 2004; 363: 970-7
6. Furukawa H, Bunko H, Tsuchiya F, et al. Voluntary medication error reporting program in a Japanese national university hospital. Ann Pharmacother 2003; 37: 1716-22
7. Kaplan H. Lessons learned. Transfusion 2001; 41: 575-6
8. Hospers J. The way the world works: the problem of induction. In: Hospers J. An introduction to philosophical analysis. 4th ed. London: Routledge, 1997: 122-5
9. Wadman MC, Muellemann RL, Coto JA, et al. The pyramid of injury: using ecodes to accurately describe the burden of injury. Ann Emerg Med 2003; 42: 468-78
10. Jha AK, Kuperman GJ, Teich JM, et al. Identifying adverse drug events: development of a computer-based monitor and comparison with chart review and stimulated voluntary report. J Am Med Inform Assoc 1998 May; 5 (3): 305-14
11. Transport statistics bulletin: road casualties in Great Britain. SB (04) 30. Department of Transport, 2004 [online]. Available from URL: http://www.dft.gov.uk/pgr/statistics/datatables-publications/accidents/casualtiesmr/roadcasualtiesingreat-britain5104 [Accessed 2004 Jul 21]
12. Altman DG. Practical statistics for medical research. 2nd ed. London: Chapman & Hall, 1992
13. Bates DW, Boyle DL, Vander Vliet M, et al. Relationship between medication errors and adverse drug events. J Gen Int Med 1995; 10: 199-205
14. Kaushal R, Bates DW, Landrigan C, et al. Medication errors and adverse drug events in pediatric inpatients. JAMA 2001; 285: 2114-20
15. Dean B, Schachter M, Vincent C, et al. Prescribing errors in hospital inpatients: their incidence and clinical significance. Qual Saf Health Care 2002; 11: 340-4
16. Lesar TS, Briceland L, Stein DS. Factors related to errors in medication prescribing. JAMA 1997; 277: 312-7
17. Dean B, Barber N. The effects of a patient's own drugs scheme on the incidence and severity of medication administration errors. Int J Pharm Pract 2000; 8: 209-16
18. Taxis K, Barber N. Incidence and severity of intravenous drug errors in a German hospital. Eur J Clin Pharmacol 2004; 59 (11): 815-7
19. Taxis K, Barber N. Ethnographic study of incidence and severity of intravenous drug errors. BMJ 2003; 326: 684-7
20. van den Bemt PMLA, Fijn R, van der Voort PHJ, et al. Frequency and determinants of drug administration errors in the intensive care unit. Crit Care Med 2002; 30 (4): 846-50
21. Hartley GM, Dhillon S. An observational study of the prescribing and administration of intravenous drugs in a general hospital. Int J Pharm Pract 1998; 6: 38-45
22. Tissot E, Cornette C, Demoly P, et al. Medication errors at the administration stage in an intensive care unit. Intensive Care Med 1999; 25: 353-9
23. Dean Franklin B, Vincent C, Schachter M, et al. Prescribing errors: an overview of research methods. Drug Saf 2005; 28 (10): 891-900
24. Wright L, Van der Schaaf T. Accident versus near miss causation: a critical review of the literature, an empirical test in the UK railway domain, and their implications for other sectors. J Hazard Mater 2004; 111: 105-10

Correspondence: Dr *Katja Taxis*, Department of Pharmacy, Division of Pharmacotherapy and Pharmaceutical Care (GUIDE), University of Groningen, Antonius Deusinglaan 1, 9713 AV Groningen, the Netherlands.
E-mail: k.taxis@rug.nl

