COMBINING RISKS FROM TWO LEADING FACTORS IN STAIR-RELATED FALLS

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Two key aspects of stairway step geometry are *nominal dimensions* of step rise and run (also known as "going") plus the *uniformity of those dimensions*. A survey of UK home step dimensions found a risk range of 0.02 to 0.10 "accidents" per year, varying inversely with runs from about 250 to 195 mm. An inverse relationship, with more variables documented, was found in earlier research in a UK laboratory with a wider range of step runs, 280 to 190 mm, as used generally in buildings. Other research identified *non-uniformity* of step run and/or rise as a potent risk factor with risk ratios estimated in one or more orders of magnitude (i.e., factors of 10). A newly identified research challenge is to determine what the overall risks are—*for a large set of stairs*—when both nominal step geometry and uniformity are jointly implicated in falls. This improves understanding of how national fall injury data might be distorted by faulty nominal and non-uniform step dimensions.

Introduction

Stairs are a major site for injurious falls whether in occupational settings, where there can be relatively good control of most risk factors, or homes, where there is little control of risk factors including those resulting from significantly lower standards for design, construction and use plus their regulation. In the USA there are relatively good national statistics, including stair-related injuries treated in hospital emergency departments, from the US Consumer Product Safety Commission (CPSC) National Electronic Injury Surveillance System (NEISS). Annual national estimates, which can be tabulated by treatment, setting, victim age, etc., are freely available on the Internet (CPSC/NEISS, 2013). Using NEISS data, analyses have been done of the disproportionate occurrence—*and relatively rapid recent growth*—of more-serious, stair-related injuries in home settings, relative to all others (Pauls, 2011).

Important environmental factors in stair-related falls have been identified over the last few decades. During this time, and in several countries, the role of step geometry has gained growing prominence. Selected highlights of this prominence include studies by researchers, in the USA, e.g., Alessi, *et al.* (1978), Archea, *et al.* (1979), Templer (1984, 1992), Hay and Barkow (1985), Cohen, *et al.* (2009); in Japan, by Kose, *et al.* (1985), Nagata (1985), Nagata and Kim (2007); and in the UK by Roys (2001), Roys and Wright (2005), Wright and Roys (2005, 2008). Other research findings include work by Johnson and Pauls (2010) and Pauls (2011). (A 20-page list of literature providing primary, secondary and tertiary treatments of stairway safety/risk factors, and associated controls including safety codes and standards, is available from the lead author.) Complementing such historical studies is extended research, for example, in major laboratories studying falls: Japan NIOSH, US NIOSH, UK HSL, Liberty Mutual Research Institute for Safety in the US, and, in Canada, the Toronto Rehab Institute iDAPT research centre—responsible for the best website on stair usability and safety research plus technology (TRI iDAPT, 2013). It is fortunate to find that physical aspects of stair construction are implicated in injuries. These aspects can be accurately measured and produced in construction and remediated after the fact of a fall.

Early estimates of stair-related injury risks

Generally, risk is described as the ratio of some outcome relative to a unit of exposure. One of the early estimates of stair-related risk was published by Archea, *et al.* (1979). The outcome measures ranged from minor missteps (defined as departures from normal gait) through to death, per stair flight use. *Flight use* is a meaningful measure of a user's encounter with a stair flight (sometimes referred to simply a *flight*, defined, like *stair*, as a single series of steps), Risks of a misstep are highest within one, two, or three steps of the transition from level walking to stair walking and in the transition from the other end of the flight in transitioning to level walking.

Table 1 provides these estimates—*based on very early NEISS data*—for the year 1975. The terminology used is exactly that used in the 1979 report. The third column, derived from the second column, was added in Table 1 to make the estimates of Archea, *et al.* more useful.

Table 1. Risk estimates for US by Archea, *et al.* (1979)

Incident type	Incidents/year	Risk per flight use
Flight uses	1,953,000,000,000	1.0
Noticeable missteps	264,000,000	1 / 7,400
Minor Accidents	31,000,000	1 / 63,000
Disabling Accidents	2,660,000	1 / 734,000
Hospital Treatment	540,000	1 / 3,617,000
Related Deaths	3,800	1 / 513,947,000

Updating early estimates of stair-related injury risks

If Table 1 were revised for conditions in the US based on NEISS national data for 2012, it would be relatively definitive at 1,297,930 for all stair-related hospital emergency department visits (growing by a 2.4 multiple). After correcting for population growth (215,973,199 to 313,933,954), this would still represent a large increase—*by a multiple of* 1.65. Rates per 100,000 population were respectively 250 and 413 for emergency department visits in 1975 and 2012. The 2012 rate for 78,876 stair-related hospitalized cases was 25.1 per 100,000 population.

Obtaining an estimate of flight uses for 2012 is problematic; the 1975 estimates by Archea, *et al.* were based on about 25 flight uses per day per person in the USA. Given many lifestyle and other changes over the intervening 37 years, we would estimate a somewhat lower per capita use of stair flights, say 20 flight uses per day. Aging of the population during this interval is a separate trend that may need to be taken into account. However, in calculating risk, this can be accounted for in estimating exposure, by lowering it accordingly.

Therefore, the 2012 risk is about one hospital emergency room visit ("Hospital Treatment" in Table 1) for every 1,766,000 flight uses, a doubling of the risk in the intervening 37 years.

Analysis by Pauls (2011) supports a doubling of the risk based on analysis of stair-related hospital-admission cases with more comparable data for the period, 1997-2009: "In the 12-year period, *age-adjusted rates (per 100,000 population)* of such injuries grew 103 percent (3.8 to 7.7) for people <65 years of age; 85 percent (36.9 to 68.1) for people ≥65 years of age."

As shown in Pauls' (2011) analysis of the NEISS data from 1974 to 2009, there was relatively modest growth of stair-related injuries in the US until 1997. Between 1997 and 2009, the ratio of all estimated US emergency department visits (and to some extent for hospital admissions) for home settings versus all other known settings grew from about 5-to-1 (the ratio between 1975 and 1997) to about 10-to-1 in 2009.

Utility of information for stair-related injury risks

In the foregoing discussion there are two different metrics used to describe risk; one typical of traffic and other safety professionals based on incidents per exposure (i.e., kilometers, hours of use), the other based on incidents per population per year. The other is more typical of public health epidemiology professionals, the source of much of the admittedly limited information about the risk of falls and the even more limited information about how and why falls occur. If there were no material changes in stair usage ("exposure") over time, the epidemiolgical approach and the safety approach should track one another.

A dramatic change began about 1997 in the relative risks of stair use in US homes versus stair use elsewhere in the US. Much of the impetus for this paper is to help make a case for research to determine how and why this happened in the US (and possibly elsewhere, including Canada). Our hypothesis is that the *combinations* of risks for these settings changed, partly due to the differences in both nominal step geometries and the uniformity of such geometries.

For example, "Top Of Flight Flaw" (TOFF), is a disturbingly pervasive, systemic non-uniformity defect in home stairs in the US and Canada, as described by Johnson and Pauls (2010). TOFF is a candidate, partial explanation for what is happening with risk of stair use. TOFF incidence exacerbates safety if occurring with other step dimension defects; for example, *systematic* TOFF might be accompanied by *random* non-uniformities in step geometry. *Both* complicate the risks coming from systemically smaller (nominal) step runs (going) in homes.

Non-uniformities, have a large impact on observable missteps on stairs as well as risk of serious injuries. Johnson and Pauls (2010) estimate impacts in orders of magnitude (factors of ten). Also, forensics-based insights have repeatedly shown that non-uniformities are often implicated as proximate causes for missteps and falls (e.g., Cohen, *et al.*, 2009).

Publications from the last decade and especially, conference presentations provide important insights from UK studies into the effect of differences in nominal step size, particularly the run (going) dimensions (Wright and Roys, 2005, 2008). As shown in Figure 1, this work, using both objective and subjective measures in laboratory and field survey work, suggests that nominal step geometry, notably the run (going) dimensions can impact actual and perceived safety by a multiple of 7 (as much as 11 for residential-type carpet covering which reduces *effective* tread run to as little as 190 mm). These multiples could be a key part of the answer along with the order-of-magnitude estimates of non-uniformity effects noted above.

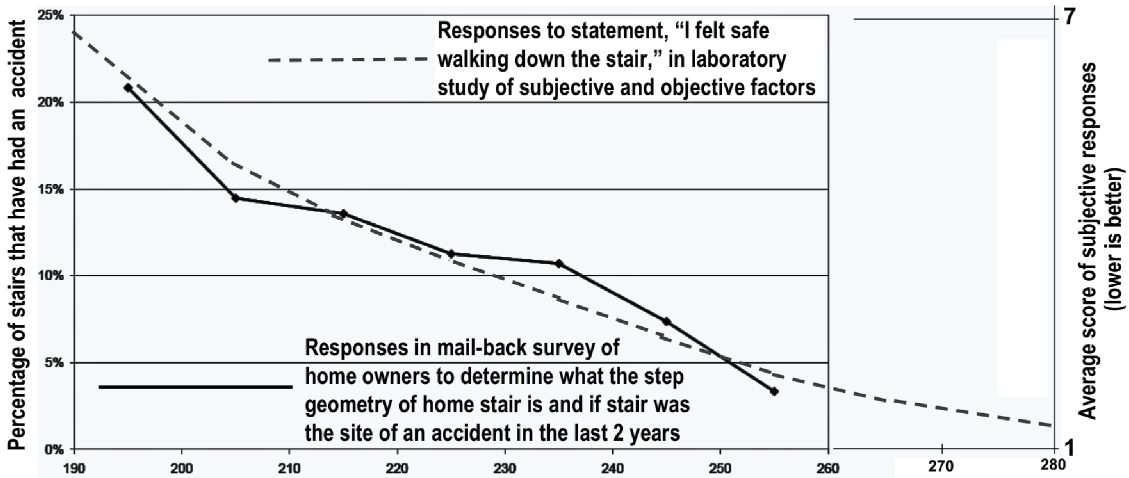

Figure 1. Graph combining results from a subjective measure of stair safety in a laboratory study with results from a survey of home step dimensions and experience with "accidents" on the stair (Wright and Roys, 2005, 2008)

Combined risks of different nominal step run or going dimensions with varying incidence of top-of-flight non-uniformities

Table 2, below, is a illustrative result of combining two risks. This is acceptable to the degree of which they can be considered as acting *independently*, linearly, and are otherwise numerically well-behaved. Not included here is a table showing results if those simplifying assumptions cannot be sustained (e.g., with *dependent* factors that require mulitiplication). An example of dependent probabilities occurs if the misstep in a TOFF situation is more difficult to mitigate due to generally short tread runs, e.g., 210 mm, permitted in Canadian homes.

Table 2. Estimated relative annual risks per 100,000 population, of US hospital emergency department visits for home stair-related falls with various nominal run (going) dimensions and with various occurrences of Top of Flight Flaw (TOFF) non-uniformity

Uniformity condition: Percentage of stairs with TOFF	**Annual injurious fall risk rates with various nominal tread runs** Risk rates shown are per 100,0000 population				
	190 mm Effective run with carpet	**210 mm** Used in codes in Canada	**230 mm** Favoured by US home builders	**250 mm** Minimum in ICC codes	**280 mm** Minimum in NFPA codes
0	230	140	110	50	20
2	250	150	120	62	**32 (Ref)**
5	260	170	140	80	50
10	290	200	170	110	80
15	**320 (10 x Ref)**	230	200	140	110
20	350	260	230	170	140
25	380	290	260	200	170
30	410	**320 (10 x Ref)**	290	230	200
35	440	350	**320 (10 x Ref)**	260	230
40	470	380	350	209	260
45	500	410	380	**320 (10 x Ref)**	290
50	530	440	410	350	**320 (10 x Ref)**
55	560	470	440	380	350
60	590	500	470	410	380

Relative risks *as affected by nominal step geometry* come from Figure 1, based on studies by Wright and Roys (2005, 2008). Increased risk posed by TOFF is conservatively assumed to be a factor of 30, based on observations by Pauls as reported in Johnson and Pauls (2010).

The 10 times criterion ("10 x Ref") is based on what has been documented for the entire US during the period 1997 to 2009, with home stairs responsible, by 2009, for about ten times as many hospital emergency department treatments as those for all other known settings. (Recall that this was compared with a multiple of only five in the 23 years during which NEISS data were collected before 1997.) In Table 2, the cell, "**32 (Ref)**," for 280 mm run combined with 2 percent incidence of TOFF, applies to US non-home stairs associated with 32 emergency department visits, per 100,000 population, for stair-related injuries during 2012.

Risks shown in Table 2, described using the surrogate measure of emergency department visits per 100,000 population, are hypothetical based on a few assumptions derived from the work of a few leading researchers into stair safety over a period 1975 to 2008 (specifically Archea, *et al*, plus Wright and Roys, 2005, 2008, along with conference presentations by the latter). Contributing to the amalgam of such diverse studies is the judgment of the lead author of this paper, using these inputs to develop first-order—*or better*—estimates of risk, expressed in units widely used in public health. These can compared with epidemiology data such as NEISS national estimates of stair related injuries in 2012 resulting, in hospital emergency department visits—at an annual rate of about 413 per 100,000 population.

It should be clear that Table 2 represents *theory-based estimates* to spur further research and analysis. These estimates are therefore superior to first-order estimates and relate most closely to US data. The authors intend that the relative risks inform the Canadian home stair safety situation with its code-permitted, 210 mm runs and evidence of much non-uniform construction.

Not included in Table 2 is the near worst-case scenario with *every* stair having non-uniformities due to TOFF (at the top of stair flights) *or* randomly located ones. These would result in estimates of about 600 to 800 per 100,000 population for the step geometries arrayed across the table. The logical end-point would be the combination of both systemic *and* random non-uniformities plus very short tread runs. Sadly, such a prospect cannot be dismissed if competencies in home construction and its inspection continue an apparent downward trend.

In Table 1, relationships among missteps and falls (from Archea, *et al.*, 1979) have been used to re-characterize the two-year "accident" survey results of Wright and Roys (2008). Both sources used the term "accident" to describe falls, but failed to be specific about severity or consequence. For example, Archea, *et al.,* used the designation "disabling accidents" to describe incidents that led to the need for some minor medical attention (i.e., either in home or in a doctor's office, urgent care center or hospital) not long-term disability.

Using injury epidemiology, we now know that, in the US, for every visit to a hospital, there are about 1.5 professional medical treatments in other settings. From this we could estimate that, for every hospital emergency department visit, there are on the order of four other treatments, either within the home or undocumented in another treatment setting. This results in a ratio of about 5-to-1 between what Archea, *et al.* termed "disabling accidents" and "hospital treatments" (their estimates being, respectively, 2,660,000 and 540,000, a ratio of 4.93-to-1, for the year 1975 in the US). With significant changes in healthcare delivery, there are and will be difficulties using the foregoing assumptions in future analyses of risk.

Discussion

Along with firearms and tobacco, stairs are among the most dangerous product we utilize in our homes in terms of public health costs, particularly relative to costs of manufacture or construction or remediation. While less recognized as being an aspect of public health, usability is also a major area where stairs, especially in our homes, exact huge costs comparable to or even greater than, the injury costs. Comprehensive, societal injury costs estimated by Lawrence, *et al.,* (1999) were on the order of five million dollars per hour in the US for 1995. With recent growth in injury costs, the current estimate is about 10-million dollars per hour in the US.

Inevitably, stair behaviour is influenced by the perception of risk (Hay and Barkow, 1985). After all, there are no falls until a user takes their first step. The perceptions of risk held by users are most veridical and hence lead to the safest outcomes when grounded in factors known to be risky from objective studies such as those summarized in this article.

In Hay and Barkow (1985) the user rankings of stairs were compared to actual fall data and to expert opinion. Naïve users, it was found, are not naïve about risks because their ranking of 40 stairs correlated r=.78 with a panel of recognized experts and r=.28 with the cost of injuries. So it is useful to relate factors empirically known to be risky such as TOFF to the degree in which *users* perceive them as risky. Moreover, as part of a comprehensive program of stair safety, users need education in stair defect identification, e.g., TOFF (Johnson and Pauls, 2010).

Regarding research, and other public health measures to better understand how stair-related risks can be assessed and managed or mitigated, *if not eliminated*, we need:

- Improved epidemiological data collection, analysis, interpretation and publication.
- Surveys of homes (and other buildings) to determine the incidence of, and factors determining, the actual dimensions of steps of stairs, taking into account nominal values as well as non-uniformities, their types, sizes, locations and conspicuity.
- Studies of adaptations people employ to detect and mitigate non-uniformities.
- Programs to educate designers, builders, regulators and others about stair risk reduction. What information is held by ergonomists and safety experts, for example, that is not communicated and worse, is not applied. How many inspectors, for example, know how to do the "crouch-and-sight test," that takes no more than ten seconds to perform? Yet it is effective and should be tried at the start of an inspection (Johnson and Pauls, 2010).
- Information on stair hazards needs to be communicated to users so as to make their perceptions of risk veridical—accurate and meaningful—as they begin their first step.

The foregoing list is incomplete and the reader, having gotten this far into this paper, will have thought of much more. Like two other papers submitted by the lead author to ICFPP2013 (and prior conferences in this series, e.g., Pauls, 2007, dealing with misstep typology), the objective is not only to spur badly needed new research but to improve our ability *now* to identify and discuss the key issues using more specific terminology than, for example, "minor accidents." Stairways—the term used to describe not only the steps but also the handrails and other features of stairs—have long fascinated a wide range of people for technical as well as many other reasons. *They clearly warrant our careful attention, and much more.*

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