Stairway Falls

An ergonomics analysis of 80 cases

By Joseph Cohen, Cindy A. LaRue and H. Harvey Cohen

FALL INJURIES in general represent an enormous burden to individuals, society and the healthcare system. According to the All Injury Program (CDC 2008), a cooperative program involving the National Center for Injury Prevention and Control, CDC and Consumer Product Safety Commission, falls are the leading cause of nonfatal injuries in the U.S. In 2003, there were 18,044 fall-related deaths; in the same year, fall-related injuries were responsible for more than 701,000 hospitalizations (State and Territorial Injury Prevention Directors Association, 2006). In addition, falls were reported to have led to nearly 7.2 million emergency department visits for which patients were treated and released (i.e., at least 1 person in 40 each year).

A recent study shows that the total number of fatal and nonfatal fall-related injuries in the U.S. in 2000 cost an estimated $26.9 billion in healthcare expenses (Finkelstein, Corso & Miller, 2006). This cost is projected to increase to $32.4 billion by 2020. Emerging research from the U.K., Canada, Sweden and Japan suggests that the fall problem is universal around the world (Haslam & Stubbs, 2006; Scott, 2005).

Since a stairway is an architectural system intended to enable a person to change elevation, falls and serious injury consequences may occur during use due to gravitational forces and contact between body parts and hard surfaces following a loss of support. Bruises, sprains and fractures are common nonfatal injuries resulting from stairway falls (Nagata, 1991). Head and neck trauma are the most common complaints among those seeking medical attention after stairway falls, with head-injured patients having a higher mortality rate than non-head-injured patients (Ragg, Hwang & Steinhart, 2000). Although many stairway falls are likely to occur in the home, injurious falls on stairways in work settings are equally problematic, especially in service occupations in which workers frequently encounter transitory conditions away from their employer's premises (Cohen, Templer & Archea, 1985).

The Present Study

This study was conducted largely in response to a report prepared for the U.S. Department of Housing and Urban Development by the National Association of Home Builders (NAHB) Research Center in 1992. In the report, NAHB researchers stated that in their opinion the bulk of stair safety research was invalid because it was based largely on controlled laboratory studies or observational studies using surrogate outcome measures, not on actual falls occurring on stairs.

The study described here is an extension of previous work that investigated retrospectively 40 actual stairway missteps, trips or slips resulting in a fall injury (Jackson & Cohen, 1995). In this study, the authors retrospectively analyzed 80 stairway fall incidents that occurred during a 15-year period (1992 to 2007). All 80 fall incidents were the subject of personal injury litigation. The objectives of this

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study were three-fold: 1) identify common causal factors; 2) validate present stairway design criteria as set forth in the International Building Code; and 3) provide further, practical scientific data to promote greater agreement as to what constitutes a safe stairway.

Abstract: *The authors retrospectively analyzed 80 actual stairway falls that led to litigation. The results confirmed nearly 30 years of ergonomics-based, laboratory and field research that has identified issues of stair geometry as a primary concern for preventing future fall incidents and injuries. The findings underscore the need for concerted attention and adherence to building codes to ensure the optimal dimensions for stair risers and treads, as well as criteria for maximum allowable variability. For industry, the findings demonstrate the utility of the ergonomics-based systems safety model for guiding efforts aimed at preventing injurious falls and other safety-related events on stairways.*

User-Stairway-Environment Systems Safety Model

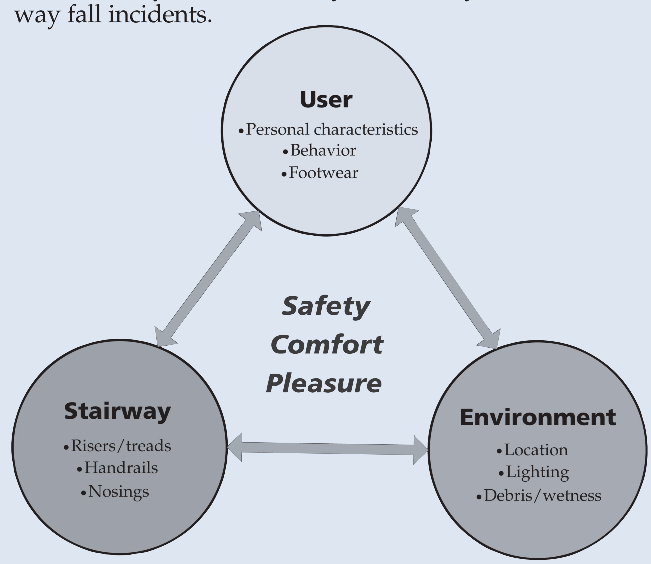
The ergonomics-based systems safety model adopted in this research served as a conceptual framework for analyzing the 80 cases (Figure 1). In systems thinking, one assumes a dynamic and interactive relationship between the elements involved in the use of a stairway—namely the user, stairway and environment of use. Harmony between the elements ensures positive outcomes when using stairways—namely safety, comfort and pleasure.

Systems thinking requires that one assumes that the three elements interact with one another. Thus, changes in one affect the other two. For example, a wood stairway that is exposed to extreme weather conditions is expected to have nonuniformities in risers and treads, which are expected to cause users to adjust their gait and, thus, increase the risk of falls. Similarly, a short tread under poor lighting conditions is likely missed by a person who walks down a stairway with certain expectations about its design.

Figure 1

Model Used for Study

User-stairway-environment systems safety model of stairway fall incidents.



Therefore, when examining stairway fall incidents, it is critical to consider not only the user's behavior, but also the stairway's characteristics, the environment of use and the interaction among them. The ergonomics-based systems safety model specifies that stairway falls most often have many contributing factors rather than one root cause.

User Factors

A stairway is an architectural system intended to allow a person to move freely in two dimensions. In other words, as a person goes forward on a stairway, s/he also moves up or down. The potential for falls exists wherever forward inertia and gravity are involved, and is further complicated in situations where there are short changes in elevation and a hard landing surface, such as a staircase (Templer, 1992). Therefore, it is important to examine the user factors in analyzing the causes of stairway falls. User factors may include one's physical characteristics (e.g., height) or footwear. However, user factors may also be behavioral in nature, such as whether the person intended to ascend or descend the stairway.

Ascent & Descent

When people move about they may fall and, especially when descending a staircase, they may fall a long way with serious injury consequences. Falls during descent typically involve overstepping while falls during ascent are often precipitated by tripping forward over the step nosing (Bakken, Cohen, Abele, et al., 2007). In the present study, 80% of the stairway falls occurred during stair descent.

Age

Although previous studies have noted the over-involvement of elderly individuals falling on stairs (Ragg, et al., 2000), this finding was not confirmed by the results of the present study, which showed a fairly wide range of age involvement—from those younger than age 20 to those age 85, with slight peaking among persons in their 40s and 50s. One possible explanation for this is that middle-aged people may have somewhat less agility to avoid falling and serious injury than younger persons, but they may not be inclined to avoid unfamiliar stair use altogether like many older persons (Jackson & Cohen, 1995).

Gender

It has been previously noted that women tend to be involved in more stairway falls than men (Templer, 1992), but men are more likely to be treated for injuries following a stairway fall (Ragg, et al., 2000). In the present study, three-quarters of the fall incidents involved women.

There are many possible explanations for this finding. Because women have a higher center of gravity (Bakken, et al., 2007) and generally less upper body strength than men (U.K. Department of Trade and Industry, 2000), they may be generally less physically able to stop a fall once they stumble and lose balance, particularly if carrying something at the time. In addition, older women are more prone to osteoporosis and other diseases that restrict fluid motion and increase the risk of broken bones. Another plausible explanation for this finding is that certain types of women's footwear force women to change their gait and balance, and may catch on step nosings or carpeting.

Footwear

Consequently, an important factor in falls that has received surprisingly little scientific scrutiny is footwear (Halford & Cohen, 2008). Johnson (1991) noted that certain types of footwear can increase the potential for falls due to poor traction or snagging. Recent research has demonstrated that falls are most likely to occur when wearing unsupported footwear, such as open sandals or flip-flops, and least likely to occur when wearing more stable and tractive athletic shoes with single-piece grip soles (Bakken, et al., 2007). In the present study, a wide variety of footwear was worn by the injured persons, including low-heel pumps (1 to 2 in.), various boots, men's dress shoes and loafers, deck shoes, tennis shoes, golf shoes, flip-flops and sandals. Some of the injured were barefoot.

Carrying Items

Some of the injured parties in the sample were reported to be carrying items, such as car keys, purses, gym bags, briefcases, boxes, stacks of files and, in a few cases, small children. This issue is important because carrying large or bulky objects may increase the probability of falling due to both physical and cognitive loading; carrying small objects, such as car keys, may also make it more difficult for a falling person to grab a support device such as a handrail.

Handrail Use

As noted in a previous observational study of handrail use (Cohen & Cohen, 2001), most persons in the present study reported that they were not using a handrail. However, as documented in another observational study (Cohen, 2000), most stairway users placed themselves within arm's reach of a handrail should they have felt the need for its use. In about 5% of the cases, handrails were not available; therefore, when the loss of balance occurred, the stair user had nothing to grasp in an attempt to regain balance.

Alcohol & Drug Use

Alcohol and drug use can have a considerable effect on a person's balance, reaction time, judgment and other psychomotor processes involved in stair use. For example, alcohol was deemed a contributing factor in 55% of injuries following a stairway fall (Bakken, et al., 2007). In the present sample, however, only 3 persons were reported to have used alcohol prior to their fall (the exact level of their intoxication was not known). One was known to be using prescription medication that might have contributed to the fall. Therefore, the impact of drugs and alcohol on the injured in the present study appears to be small.

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Environments of Use

The environment in which a person uses the stairway can be another important factor. This can include conditions related to location (indoors/outdoors), weather, lighting, moisture and debris.

Location

The location of the stairs involved in a fall is an important consideration. The location suggests how much traffic (exposure) the stairs receive and how much wear they might endure from the elements. Nearly two-thirds of the investigated stairs were located in public places, such as hotels, restaurants and office buildings, while the remaining one-third occurred in residential areas, such as homes and apartment complexes.

Of the 80 cases, 65% of the staircases were located outdoors while the remaining 35% were located indoors. This finding, too, is somewhat contrary to previous studies which suggest that most stair falls occur in the home (Templer, 1992). It must be noted, however, that most of the incidents analyzed in this study occurred in the southwestern U.S., predominantly in Southern California. The climate and resulting lifestyle characteristics of this environment may promote a greater number of outdoor stairs (as maintenance is less of a concern). In addition, fewer homes have basements or multiple levels. Furthermore, because the cases reviewed for this study involved litigation, one might expect that more of the falls would have occurred in public places.

Table 1

Factors Associated With Stairway Fall Incidents

This table summarizes factors associated with the 80 stairway fall incidents reviewed in this study.

Factor	Percentages
User factors	
Descent/ascent	80%/20%
Women/men	75%/25%
Age	Varied
Footwear	Varied
Environments of use	
Public/private	66%/34%
Outdoors/indoors	65%/35%
Debris-wetness not present/present	67%/33%
Daylight/after dark	75%/25%
Lighting implicated	34%
Stairway characteristics—dimensional inconsistencies	
Riser variations > 0.375 in.	60%
Tread variations > 0.375 in.	34%

Photo 1: This stairway has high degree of variation in both riser heights and tread depths. If a riser is too high or too low, a person navigating the stairs may find it difficult to maintain safe footing. Treads that are too short force the stair user to either rest only part of a foot on each tread or to twist the foot unnaturally.

Table 2

Stairway Riser Heights & Tread Depths

A summary of the stairway riser heights and tread depths in the present study.

Factor	Min	Max	Most frequent
Risers	3.5 in.	10.375 in.	5 to 7.5 in.
Treads	8 in.	35 in.	10 to 12 in.

Note. N = *80.*

Lighting

Illumination of stairway treads increases the probability that the user will see them and plant his/her foot safely. Of course, the amount of available illumination for any given staircase is likely to change throughout the course of a day. Of the 80 cases analyzed, nearly three-quarters took place during daylight hours. The amount of light available ranged from no measurable light to 6.65 foot-candles. For safety, Maynard and Brogmus (2007) recommend 20 foot-candles of local spot or floodlight illumination. Nevertheless, as reported in the earlier study of 40 falls (Jackson & Cohen, 1995), insufficient lighting played, at best, a small role in the 80 fall incidents reviewed.

Debris/Wetness

Stairs that are wet or cluttered may be more hazardous. Sand, mud, algae, ice, snow, water, poorly maintained carpet or foreign objects may cause people to lose their balance if they step on them. The problem may be magnified in cases where the lighting is poor and the objects cannot be clearly seen or anticipated. However, in the cases examined, two-thirds of the stairways were dry and/or debris-free at the time of the fall, indicating that debris/wetness were not contributing factors in most cases.

Stairway Characteristics

Following the user-stairway-environment systems safety model, prevention of falls on stairways should focus not only on the user and the environment of use, but also on the design, construction and maintenance of the stairway itself. Ergonomics principles indicate that it may be far easier to change the stairs and/or the environment of use than the stair users.

Table 1 (p. 29) summarizes the factors associated with the 80 stairway falls analyzed in this study. In examining the cases, considerable variation was found in terms of user and environmental factors. Certain factors, such as the age of the injured person and stair location, were so varied that little could be shown in the way of trends or patterns. Other potential factors, such as drug use and stair lighting, were found to be involved in only a few cases. The most consistent factor implicated in the 80 stairway falls is the stairway geometry.

Riser & Tread Dimensions

One primary point of contention among those involved in stairway construction has been the acceptable dimensions of risers and treads. In a laboratory study, Irvine, Snook and Sparshatt (1990) examined how subjects navigated 19 sets of staircases with varying riser and tread dimensions. They found that the difficulty with which one could use a staircase was affected by the person's age, gender and body dimensions. The most acceptable dimensions they found across the variables were 7.2-in. risers and 11- to 12-in. treads. Deviations in riser height were found to be more difficult for subjects to deal with than moderate changes in tread length (run). Interestingly, the data acquired during this field study of actual stair falls parallels the findings of laboratory studies as the number of injury cases involving excessive variation in riser heights is 25% greater than those involving excessive variations in tread lengths.

The International Building Code (IBC) states that risers should measure between 4 and 7 in. The IBC also states that treads should be no less than 11 in. in length. These dimensions tend to agree with those Irvine, et al. (1990) found to be most comfortable for their subjects.

If a riser is too high or too low, a person navigating the stairs may find it difficult to maintain safe footing. Risers higher than 7.5 in. require excessive energy for most people to climb, and may increase loss of balance when descending (Templer, 1992). If treads are too long, they force the person using the stairs to adopt an awkward, stretching gait, or to take one and a half to two steps, often resulting in a misstep off the step edge. Treads that are too short force the stair user to either rest only part of a foot on each tread or to twist the foot unnaturally (called "crabbing"), so that the foot rests entirely on the tread. Any of these situations is likely to increase the potential for a fall (Jackson & Cohen, 1995; Templer, 1992).

Table 2 summarizes the riser and tread dimensions in the 80 analyzed cases. In this investigation, the shortest riser found measured 3.5 in. and the highest measured 10.375 in. For the most part, the risers in this investigation ranged from 5 to 7.5 in. The treads in this investigation ranged from 8 to 35 in., with the treads of most of the staircases falling between 10 and 12 in. Photo 1 shows a stairway with a high degree of variation in both riser heights and tread depths. The top tread narrows down to 2 in. on the far left side. This extreme dimensional variation, combined with the excessive slope of the walking surface, lack of a handrail and insufficient lighting created a very unsafe stairway.

Dimensional Inconsistencies

When the riser heights or the tread length on a stairway are inconsistent, a person using the stairs must unknowingly adjust his/her gait considerably and frequently. These adjustments may not be visually obvious, but they can have significant impact on the balance of the stair user. Stairs with irregularities as little as 0.25 in. between adjacent risers and runs can disrupt the rhythm of a person's step enough to cause a fall (Johnson, 1991; Templer, 1992). Minimal variation between successive risers and treads is essential to ensure smooth gait and to match users' expectations of the walking surface characteristics.

According to the Uniform Building Code, which was pervasive throughout the western U.S. and the IBC, its successor since 2000, the differences among riser height or tread length on a staircase must not vary more than 0.375 in. The Building Officials and Code Administrators (BOCA) code, which was pervasive throughout the Midwest before 2000, also states that the difference between the largest and smallest risers on a staircase shall not exceed 0.375 in. The BOCA code further states that the difference between the heights of adjacent steps must not exceed 0.1875 in.

Sixty percent of the stairs in this study were found to have riser variations of greater than 0.375 in. The greatest variation was a stairway with a 6-in. variation in the riser heights. The average riser variation for the investigated cases was approximately 0.625 in., a full quarter-inch more than the amount of variation allowed by the model codes. Explanations for these variations include the natural settling during the life of the staircase, poorly maintained structures and conformance to fit existing sidewalk or terrain, as well as design and construction flaws.

Approximately one-third of the stairways ($n = 24$) where tread lengths were measured had tread variations exceeding the 0.375-in. criterion. One tread varied from 2 in. on one side to 20 in. on the other. Other than that step, the greatest case of tread variation in a stairway was found to be 3.875 in. The average tread variation of those measured was 0.5 in., likewise exceeding the 0.375-in. maximum variation criterion for each stairway.

Nosing Strips

Another factor appearing in the data was nosing strips along step edges. Designed to help define the edge of the step, highly conspicuous nosing strips help cue the stair user to the presence of the step edge. However, the strips can create hazards if they are poorly maintained. Falls in this study occurred due to stair users tripping over uplifted strips or nails protruding from the strips, misstepping on loose or broken strips, and slipping on the metal surface material. However, problems involving nosing strips did not lead to a significant number of falls in the cases comprising this study group.

Photo 2: This half-round stair has an unusually long tread. The step edges could be made more conspicuous with hazard yellow striping and an intermediate handrail. Also note the deceptive visual cues created by nearby expansion joints, and the adjoining ramp handrail (to the right) which is excessively long.

Example Stairway Fall & Incident Analysis

A young woman in her mid-20s was exiting a rear stairway of a school to which she had recently been assigned as a student teacher when she misstepped and fell severely, fracturing the ankle of her leading leg. She was not accustomed to using this stairway. She was neither in a hurry nor was she carrying anything substantial.

Photo 2 depicts the stairway in question. The half-round stair has an unusually long tread (35 in.), the edge of which was not conspicuously marked with, for example, hazard yellow striping. The lack of an intermediate handrail more within the normal line of sight also was considered to be a contributing factor to the injury incident. Such a handrail would have provided a more obvious visual cue to the subtle change in elevation.

Deceptive visual cues, including the presence of expansion joints that blend in with the grooves along the step edges, as well as an exceptionally long handrail to the right (as one descends the stairway) and one bordering the left edge of an adjoining ramp, were also implicated as contributing factors.

Conclusion

The findings of this retrospective analysis suggest that a wide variety of variables need be considered in the prevention of stairway-fall-related injuries. In addition to the more obvious ways of preventing stairway falls (e.g., keeping them clean, dry, uncluttered, well-maintained and well lit), the uniformity of stairway risers and treads themselves must be given concerted attention during design and construction. The findings also suggest that anyone who investigates stairway falls should use an ergonomics-based systems safety approach. This study indicates that stairway users are too often blamed for injuries that result from stairway and environmental factors.

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In this analysis, excessive dimensional variation appeared to be the most pervasive factor in stairway fall causation, followed by noncompliance with the 7-11 design rule for risers and treads, respectively. As with dimensional variation, this investigation showed a tendency for staircase geometry to fall outside the recommended limits of established building codes. Therefore, stairs that do not follow these requirements are more likely to be involved in falls.

It stands to reason that greater adherence to the criteria specified in existing codes (i.e., risers in the range of 7 in. and treads in the range of 11 in.) would decrease the number of actual stairway falls that occur. Therefore, it is essential for both architects and builders to adhere to existing codes regarding stairway dimensions. Furthermore, prevailing codes must be enforced by building code officials, plan checkers and field inspectors, since stair dimensions can often be overlooked in the haste to issue building occupancy permits.

The use of stairway information from litigated cases proved quite helpful in identifying factors that lead to actual fall incidents. However, a few notes of caution should be heeded when conducting this type of a study. The primary concern is that since most cases are part of the legal process, the information was gathered well after the incident occurred. Therefore, one must rely on the memory and accounts of the plaintiff and any witnesses as to what led to the incident; if the information is not critically evaluated and confirmed by other sources, this may introduce bias.

Also, documentation of the environmental conditions as they existed at the time of the incident is rarely available. Since none of the stairways in the cases analyzed were altered after the incidents, it was possible for the research team to collect stair measurements and other quantifiable data, such as available lighting, as they were at the time of the fall.

Other areas where ergonomics research bearing on improved stair safety design is currently being directed includes detailed usability criteria for so-called graspable handrails; the optimal projection of step nosings; standardized markings under varied circumstances, both visual and tactile, for added conspicuity and reduced masking of step edges; as well as softening designs that make stairs more forgiving or less injury-inducing during impact. ■

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