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# The Effects of Interactive Stairways on User Behavior and Safety

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**Abstract.** The social context for stairway design in multi-story buildings is changing. At one time, stairways were viewed primarily as a means of egress in an emergency, and elevators or escalators were the primary method of vertical circulation with the exception of monumental "feature" stairways. Today, the emphasis is changing to promote the use of stairways in buildings as opposed to use of elevators due to the health benefits of stair climbing. This is providing an opportunity for architects and building owners to experiment with innovative designs. One interesting innovation is the "interactive stairway." Little is known about the impact of these interventions on the rate of stair accidents. The purpose of this study was to assess the safety of interactive stairway designs by comparing the user's behavior and the incidence of unsafe stair use on two interactive stairways with a stairway made of conventional material. A checklist for recording observations of stair users was developed. Observations were conducted in two museum buildings with interactive stairways and in one university building with a conventional stairway. Safety-related behaviors and incidents on the interactive stairways (CM and SM) and the conventional stairway (SU) were documented and compared. On the interactive stairways, more stair users glanced down at the treads (CM: 90%, SM: 81% vs. SU: 53%); fewer stair users diverted their gaze away from the stairs (CM: 22%, SM: 32% vs. SU: 66%); and handrail use was higher (CM: 40%, SM: 33% vs. SU: 28%). Incident rates were similar across the stairways (CM: 2.2%, SM: 2.2%, SU: 2.6%). The research suggests that interactivity can improve stair safety if used appropriately.

**Keywords.** stair safety, stairway design, interactivity, behavior, universal design, assessment, observational study, visual attention.

## Introduction

Stairways are one of the most dangerous parts of the built environment. In a flight of stairs, each step is a physical obstacle that can interfere with foot clearance and cause a person to lose balance and fall. The risk is exacerbated by flaws in the design and construction of stairways [1,2], such as non-uniformity of risers and treads, which often become the subject of litigation [3]. Moreover, users often do not perceive stairways as being dangerous unless stair defects are visibly noticeable [4]. In the U.S., stair-related injuries result in 1,900 deaths [5] and 1.3 million hospitalizations per year [6]. The risk estimate is one hospital emergency room visit for every 1,766,000 flights of stairs climbed [4]. It is also estimated that the annual cost of stairway injuries is 100 billion dollars in medical and litigation expenses, which is significantly higher than the cost of

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building or improving existing stairways [7]. The statistics suggest research needs for assessing current practices and knowledge gaps for design of stairways.

Since the advent of elevators, stairways have been hidden in multi-story buildings with less than desirable qualities, often as a result of being overlooked in the design process. In recent years, however, there has been growing interest in the role of stairways in promoting health and active living, particularly in part to reduce obesity rates in the U.S. [8-10]. The health benefits of stair climbing include improved weight control, cholesterol levels, lower-limb strength, and cardiovascular fitness [11,12]. In 2013, New York City Mayor Michael Bloomberg issued an executive order to promote the use of stairways over elevators in new and renovated City buildings [13]. Accordingly, architects should design highly visible, easy to access, and attractive stairways [14]. “Interactive stairways” are one thread of activity related to this new emphasis in design practice. While interest is growing in stair use on both architectural and policy levels, much less emphasis is being placed on stair safety. For example, studies have examined the effectiveness of features such as signs, artwork, and music to increase stair use [11,15,16], but, to our knowledge, no studies have attempted to assess the impact of these interventions on user safety. These studies would be warranted simply because a higher frequency of stair use, for any reason, increases the exposure to risks of falling. But, interactive stairways could cause distraction from the stair climbing task and alterations in gait while traversing the stairway.

Compared with other interventions, interactive features have shown a significantly higher impact on stair use and thus greater promise for stairway design as a means to encourage physical activity [16]. In this study, we consider interactive features such as sound effects, embedded LED, and technologies that affect the entire stairway as opposed to individual elements such as interactive art hanging along stairway walls or attempts to turn the entire stairway into an artwork with paint, sculpture or stair configuration. These features can change the purpose or the "imageability" of stairways in buildings by allowing users to engage in stair climbing tasks while feeling as though they are having an influence on the built environment [16,17]. Moreover, interactive stairways are able to detect movement on the stairs through sensor technology which allow users to sense their own movements as feedback is triggered. Perhaps the best known example of this type of stairway was the "Piano Stairs" at the Odenplan subway station in Stockholm, which was part of Volkswagen's "The Fun Theory" campaign in 2009. This subway stairway, located next to an escalator, was modified to look like a piano keyboard and play musical sounds when users ascended and descended. The goal was to increase stair use by making the stairway fun to use. A 66% increase in stair use was reported [18].

This study investigated the effects of interactive stairways on user behavior and safety by comparing behaviors and incidents on these stairways with a conventional stairway design. In the U.S., interactive stairways are gaining popularity, especially in museums as technology exhibits. This presented some opportunities to learn more about their impact. Our research focused on two issues – visual attention and use of safety features. First, since stair safety is largely affected by visual attention [1,19,20], any distractions caused by the interactive system could reduce gaze fixation on the stairs, and thus increase the risk of tripping, slipping or falling. However, since stair users are likely to exercise more caution in the presence of known distractions [1,2], interactivity could also increase visual attention to the stair use task as a compensatory behavior, mitigating any negative impact on safety. Second, interactive stairways motivate people to use the stairs in unconventional ways. For example, sounds effects that are triggered by movements often cause people to run, jump, skip, and even dance on the steps. To maintain safety, users may rely more on safety features such as handrails, slip resistant treads, and visibility of stair tread edges.

## 1. Methods

### 1.1. Hypotheses

The following hypotheses guided the observational research:

- HI: Interactive stairways attract the user's gaze to the stairway itself.
- H2: There will be less diverted gaze to the surroundings.
- H3: There will be more handrail use on interactive stairways.

### 1.2. Protocol

The University Institutional Review Board determined that our research did not meet the definition of human subjects. We did not gain any personal information about people through intervention or interaction therefore no IRB approval was needed for the project.

### 1.3. Feasibility Test

Video recording was chosen as the study method as recordings could be replayed repeatedly for analysis purposes. It has also been used in prior studies of stairway incidents [1,21,22], although earlier studies were limited due to the technological constraints and high costs of video recording at the time. Prior to the implementation of the research, a pilot study was conducted to determine the feasibility of using video recording to collect data, during which the observer became familiar with recognizing stair behaviors and precipitating factors for stair incidents.

### 1.4. Site Selection

Two interactive stairways, one at the Children's Museum of Pittsburgh (CM) and one at the Science Museum in Boston (SM), were selected as the sites for observations (see Figure 1). One other public stairway, without interactive features, at the University at Buffalo Student Union (SU) was identified as the comparison site.

The Children's Museum stairway (CM) was equipped with sensor stair pads made of vinyl composition tile in green color that activated sounds of children's voices from speakers when pressure was applied to the surface. The stair pad system was installed only on one side of the stairway, for the right-side ascending path, and did not stretch across the entire stair width. This stairway had sixteen risers per flight, two flights of stairs, and handrails for both adults and children in an enclosed space that obscured most of the surrounding views (see Table 1).

The Science Museum stairway (SM) used invisible light beams to detect stair users and activate sounds. Detection occurred when users crossed light beams between photoelectric sensors and reflectors that were located at opposite sides of every step. The sounds changed in pitch and melody based on the user's patterns of ascending and descending. The CM stairway was longer in length, and narrower, whereas the SM stairway was more open and wider which allowed more people to use the stairs simultaneously. The CM stairway had graspable handrails, including one for children, but the SM stairway handrails were too wide to grasp. The comparison site had views from the stairs and location prominence, which are conditions similar to those in the Science Museum. Table 1 summarizes the differences.

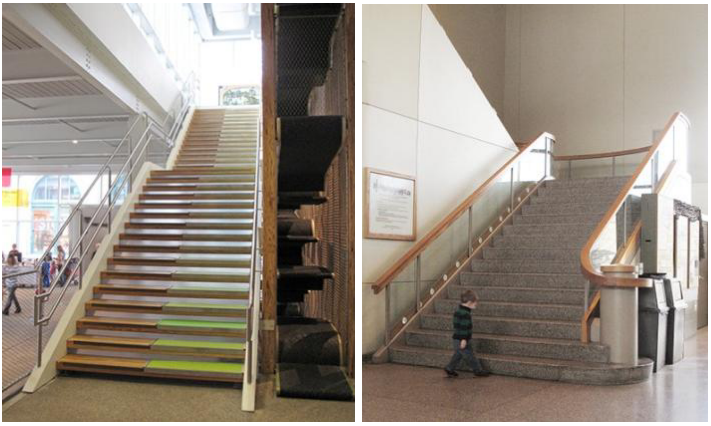

**Figure 1.** Interactive stairways at a Children's Museum (left) and a Science Museum (right).

**Table 1.** Profile of the stairways in the museum buildings and the university building.

| | **Children's Museum (CM)** | **Science Museum (SM)** | **Student Union (SU)** |
|---|---|---|---|
| Views from the stairs | Partial | Yes | Yes |
| Tread edge contrast | Only on one side | No | Yes |
| Tread depth | 12 in (305 mm) | ≥ 11 in (279 mm) | 11 in (279 mm) |
| Riser height | 5.8 in (149 mm) | 6.7 in (171 mm) | 8 in (203 mm) |
| Riser count (top) | 16 | n/a | 10 |
| Riser count (bottom) | 16 | 15 | 13 |
| Handrail width | 1.5 in (38 mm) | 3.5 in (89 mm) | 2.25 in (57 mm) |

## *1.5. Checklist Development*

An observation checklist was developed to record information on a stair user (see Figure 2). The checklist included information about demographics, key safety-related behaviors (tread gaze, diverted gaze, and handrail use), typical behaviors (talking, using electronic devices, and carrying things), and noticeable stair incidents. Stair incidents included hesitation, losing balance and missteps which, in this study, are considered "precursors of falls."

Tread gaze, or observed glances at treads, is a key safety-related behavior because visual scanning of treads is important for depth perception, foot placement [1,19,23] and postural control [20,23]. Depending on how safe the stairway appears to the user, tread gaze occurs either frequently or infrequently and can be measured by the number of gazes per step, e.g. once every seven steps taken [2]. Frequent tread gaze was defined as glancing at the treads three or more times throughout an entire flight of stairs, and infrequent tread gaze as frequencies of two or less times. Glances were measured each time the user's head turned downwards toward treads. For safe negotiation of long stairway runs, one glance may be necessary at the beginning, middle, and end phases of stair walking, or the transitions and middle steps of a flight of stairs [20]. Thus, three glances were used as a threshold of safe attention to the stair climbing task.

Diverted gaze and handrail use were included as behaviors to observe as these variables could indicate several aspects of stair use including user comfort, distraction, and caution on the stairs [1,2].

| | Stair users | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **Age** | | | | | | | | | |
| Child (ages 1-14) | | | | | | | | | |
| Young Adult (ages 15-24) | | | | | | | | | |
| Middle-Aged Adult (ages 25-64) | | | | | | | | | |
| Older Adult (ages 65+) | | | | | | | | | |
| **Gender** | | | | | | | | | |
| Female | | | | | | | | | |
| Male | | | | | | | | | |
| **Key Behaviors** | | | | | | | | | |
| Frequent tread gaze (3 or more glances at the treads) | | | | | | | | | |
| Infrequent tread gaze (2 or less glances at the treads) | | | | | | | | | |
| Diverted gaze | | | | | | | | | |
| Handrail use | | | | | | | | | |
| **Typical Behaviors** | | | | | | | | | |
| Talking | | | | | | | | | |
| Using electronic devices | | | | | | | | | |
| Carrying things | | | | | | | | | |
| **Noticeable incidents** | | | | | | | | | |
| Hesitation | | | | | | | | | |
| Loss of balance | | | | | | | | | |
| Misstep | | | | | | | | | |

**Figure 2.** Observation checklist.

### *1.6. Collection and Recording of Data*

Two hours of video were used to analyze stair users in descent only, due to limitations of video angles that make it difficult to observe people ascending. For example, at points near the front and bottom of stairs, it is not possible to clearly see the ascending user's head/eye movements since their backs are turned. Video recording was conducted by the first author at the Children's Museum (CM) on a Friday and at the Science Museum (SM) on a Sunday between 12:00 and 14:00. Observations were collected at the comparison site (SU) on a Tuesday and Thursday in the late afternoon. At each site, the video recorder was positioned to capture stair users from head to foot within 20 feet of the stairway. To be unobtrusive, the observer either sat with the recording device in a seating area or sat in a seating area a few feet away from the video recorder. Data from the video recordings were coded and analyzed using a computer based video processing program. Stair incidents were recorded on the checklist, extracted from the video data, and time-stamped so that examples of unsafe stair use could be located easily for further analysis.

## 2. Results

A total of 92 stair users in the Children's Museum (CM), 502 stair users in the Science Museum (SM), and 453 stair users in the Student Union (SU) were observed. The incidence of hesitation, misstep, and loss of balance as a percent of all stair descent was similar across all three samples (CM: 2.2%, SM: 2.2% vs. SU: 2.6%) (see Table 2).

**Table 2.** Cross-site comparison of the incidence of unsafe stair use.

| | **Children's Museum (CM) (*N* = 92)** | **Science Museum (SM) (*N* = 502)** | **Student Union (SU) (*N* = 453)** |
|---|---|---|---|
| Hesitation | 1.08% (1) | 0.39% (2) | 1.54% (7) |
| Misstep | 0.0% (0) | 0.39% (2) | 0.22% (1) |
| Loss of balance | 1.08% (1) | 1.19% (6) | 0.88% (4) |
| Fall | 0.0% (0) | 0.19% (1) | 0.0% (0) |
| **Total** | **2.17% (2)** | **2.19% (11)** | **2.64% (12)** |

In the Children's Museum, 4% (4) of the users repeatedly used the stairway. Nearly 23% (21) of the users walked on the sensor stair pads along their left-side descending path, which is considered the "wrong" side of the stairway. One stair incident (50%) occurred as a result of intentionally using the interactive feature. In the Science Museum, 17% (86) of the users repeatedly used the stairway. Twenty-seven percent (3) of the stair incidents occurred from these repetitive uses. There was no repeated use of the SU stairway.

Hesitation or sudden disruption in walking movements occurred at a slightly lower rate in the Science Museum (SM: 0.4% vs. CM: 1.1%, SU: 1.5%) (see Table 2). Loss of balance rates were virtually the same across the buildings (CM: 1.1%, SM: 1.2%, SU: 0.8%). Misstep rates were higher in the Science Museum (0.4%) compared to 0.2% in the Student Union; no missteps occurred in the Children's Museum. One fall (0.2%) was observed in the Science Museum as a result of a child jumping on the stairs.

On the interactive stairways, more stair users glanced down at the interactive steps than the conventional steps (CM: 90%, SM: 81% vs. SU: 53%) (see Figure 3). Frequent tread gaze was involved in 100% (2) and 82% (9) of the incidents compared to 42% (5) on the conventional stairway; in the Student Union, stair incidents were more associated with infrequent tread gaze (58%). Fewer stair users diverted their gaze away from the interactive stairways (CM: 22%, SM: 32% vs. SU: 66%) (see Figure 3). When returning attention to the stairway, users may have a tendency to re-orient themselves by glancing at the stairs. It was noted that diverted gaze was involved in fewer stair incidents in the museum buildings, CM: 50% (1), SM: 36% (4), than in the Student Union (92% or 11).

Handrail use was highest in the Children's Museum and lowest in the Student Union (CM: 40% vs. SM: 33%, SU: 28%) (see Figure 3). The rate of handrail use in the conventional stairway supports research findings that handrail use is often minimal [24]. The results support our hypothesis that stair users would display more compensatory behavior by looking at the tread more, looking less at the surrounding environment, and by using the handrail more. The study did not find any significant patterns among age groups nor in typical user behaviors (talking, using electronic devices, and carrying things).

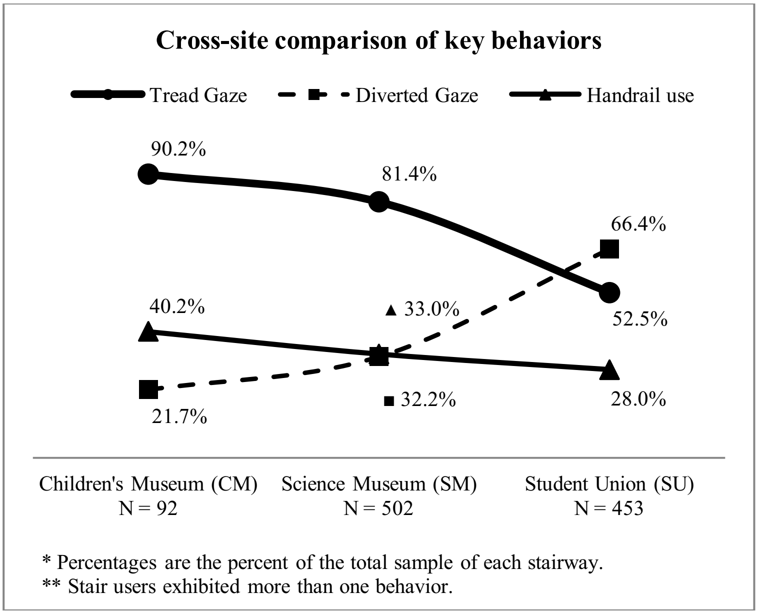


**Figure 3.** Cross-site comparison of key behaviors.

## 3. Discussion

The incidence rate for hesitation, misstep, and loss of balance were similar across the stairways. But, users gazed more frequently toward the treads and used the handrails more frequently on the interactive stairways, demonstrating that the awareness of potential safety risks leads to compensatory behavior. On the conventional stairway, stair users tended to focus their visual attention on the surrounding environment rather than the treads and used the handrail less frequently. When a hazardous condition is not perceived, users do not take compensatory action. Although we observed greater incidences of tread gaze and handrail use on the interactive stairways compared to the conventional stairway, we did not observe differences in altered gait, suggesting that these behaviors compensated for the distractions the interaction may cause. But, we also found that tread gaze was involved in most of the incidents on the interactive stairways. These results suggest that novel events can capture the user's attention in an involuntary way to focus attention to a potential danger but, at the same time, distract attention away from the task at hand. Distraction could be related to the nature of the stimuli. For example, random and novel noises could be distractions but music more focusing.

Among experts, prevailing wisdom is that the most dangerous risks are those that are not perceivable. This opinion seems to be confirmed by this study. But, at this point there is not enough data to justify a conclusion that interactivity per se either creates safety hazards or increases safety. Previous studies demonstrate that people may have difficulty perceiving certain risks of stairways even though they should be obvious. Furthermore, the novelty of interactivity could lead to increased vigilance and handrail use initially that is not sustained as users become accustomed to the interactive features.

The deployment of interactive stairways is intended to enhance a museum visitor's experience. But it is important to learn more about how interactive design strategies actually affect stair safety behavior especially when adequate safety features, like graspable handrails, are not present. Interactive features increase exposure to risk. For example, in the Children's Museum, a misstep occurred when a stair user intentionally walked on the "wrong" side of the stairway in order to interact with the stairway. In the Science Museum, 27% of the incidents were a result of repeated use of the interactive stairway, especially by children. It’s not surprising that interactive features appealed to children’s curiosity and sense of play so a group of children was easily motivated to using the stairways. Designers who are exploring digital technologies to enhance the stair climbing experience should take notice because this puts children at greater risk of accidents. For example, when retrofitting existing stairways to interactive features, handrails should be provided to compensate for unconventional stair behavior. The Science Museum currently has ungraspable handrails that are also unreachable to small children.

Interactive stairways can indeed be more inclusive and engaging environments. Our observations revealed repeated use of the interactive stairway in the Science Museum among all age groups, demonstrating their appeal. But, understanding and applying this technology requires more than just designing attractive stair features. It is important that these installations do not create potential unsafe conditions. In the Children's Museum, for example, installation on only half of the stairway enticed stair users to intentionally walk into opposing traffic in descent. Motion sensors, which do not directly impact gait, are clearly less intrusive than pads applied to the treads. An increased public awareness is also necessary to reduce accidents. For instance, adults should caution children when using interactive stairways or restrain children from using interactive stairways when safety hazards are present.

It should be noted that there are interactive stairway designs that could be much more dangerous than those studied, for example, the use of dynamic LED color displays and a painting incorporated into stairways create optic effects (see Figure 4) that can camouflage the edges of the treads. Additional research in this area could be very beneficial to identify what is dangerous and what is not, but education for museum administrators is also needed to acquaint them with the potential hazards and how to suitably protect people from exposure to risk, e.g. use of signs and barriers.

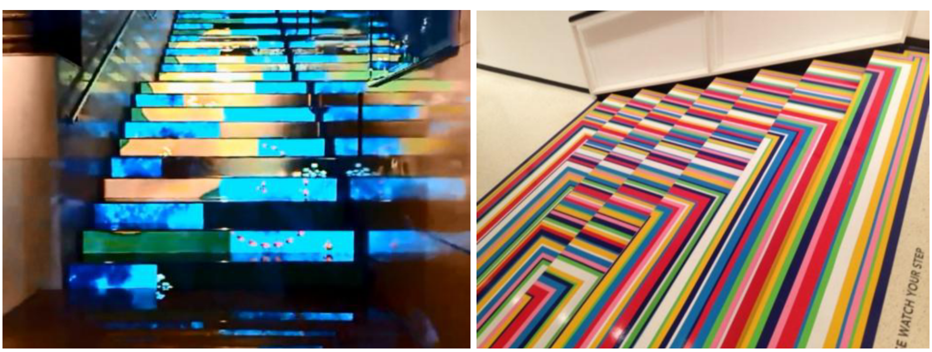


**Figure 4.** a) Left – a stairway with LED color displays on stair risers, b) Right – a stairway painted as an art piece

The study had several limitations. It compared stairways with different characteristics using only two hours of observations. Longer or more frequent observation periods could produce different results, although the short observation period did result in reasonable sample sizes. Studies of stairways that are more comparable in design would provide more direct comparisons of targeted stair features, particularly before-and-after comparisons of installations. In addition, a larger sample would provide more data on the impact of those features on different age groups; this study did not have enough data for each age group to analyze this relationship.

Although the study was based on naturalistic observations rather than automated data collection of user behavior such as the use of an eye-tracking device or motion analysis, the video recording method allowed the observer to track head movements that were purposefully aimed downwards, which is strongly suggestive of gaze aimed at the treads. The study demonstrated that the use of video recording for observations of stair use is an inexpensive and easy to implement method for assessing stairway design features that are being used in public places without appropriate research evidence.

Further studies using this empirical method would add to our knowledge of contemporary stairway designs and contribute to improving the usability and safety of stairways for diverse users. Laboratory studies could contribute further toward this developing knowledge base. In a laboratory, more sophisticated measurement tools like eye gaze systems, motion analyses, and force plates can be used. Moreover, different types of interaction can be studied and varied systematically. Laboratory research would not only increase our knowledge about the issues related to interactive stairway design but also be useful in testing concepts before they are implemented in public places. Other contemporary practices, such as open risers, glass stair treads, and embedded LEDs clearly require similar research attention.

## 4. Conclusion

Stair safety can be improved by understanding the impact of stairway design interventions on the rate of stair incidents. Interactive stairways were assessed by observing stair users and comparing the incidence of unsafe stair use on two interactive stairways in museum buildings with a stairway made of conventional materials in a university building. We identified differences in the behavior of stair users (tread gaze, diverted gaze, and handrail use) between the stairways. The results indicated that interactive stairways can be as safe as any other stairway but they do alter stair use behavior. The research technique used in the study should be used to evaluate more contemporary stairway design features. An interesting finding from this work is that interactivity appears to increase vigilance while negotiating a stairway and handrail use. On the one hand, this may be a result of perceived safety risks that could otherwise be avoided. But on the other, it suggests that interactivity, in some form, can be used to increase safe behavior on stairways. The introduction of lighting at stair edges, flashing lights to bring attention to handrails, sounds that provide feedback on progress along the stairway or even as a caution to unsafe behavior, all may prove useful as countermeasures to the inherent risk of stair climbing.

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