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Study of Factors Associated with Risk of Work-Related Stairway Falls

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This report describes a study of stairway risk factors based on video tape recordings of workers using 31 flights of stairs selected from among the industries with the highest frequency and severity rates for stair-related injuries. The video tapes were reviewed to identify all incidents, i.e., falls, trips, slips, missteps, and moments of temporary instability. The characteristics of the 98 stair users who were involved in an incident were compared to the characteristics of a matched group of stair users who did not have incidents. The factors that best discriminated between the incident group and the nonincident group were: (a) The incident group tended to be those whose movement was impeded by others and who were older; and (b) The nonincident group tended to be those who were wearing glasses and those who were very large or heavy individuals. The influence of stairway physical features on the risk of injury was examined using correlation analysis. The measure of risk was the incidence rate (observed incidents per number of observed uses) for each flight as well as for each tread. Among the several variables significantly correlated with higher incidence rate are: (a) higher effective riser height and less effective tread depth; the safest stairs have an effective riser height not greater than 7 in. (18 cm) and an effective tread depth no less than 11 in. (27 cm); and (b) for descent only (92% of the injuries), the size of the nosing projection; it appears that nosing projections that exceed 11/16 in. (1.8 cm) are associated with higher incidence rates.

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It has long been recognized that stairs are among the most serious accident hazards that individuals encounter in the everyday environment (Brill & See, 1971; Merrill et al., 1957; U.S. Dept of Housing and Urban Development [HUD], 1972). The magnitude of the stair accident problem has become even more apparent since 1973 when the U.S. Consumer Product Safety Commission (CPSC) began issuing systematic reports of the frequency and severity of accidental injuries resulting from the use of a wide range of products and environments. According to the data reported by CPSC's National Electronic Injury Surveillance System (NEISS) there are over 500,000 injuries resulting from stair accidents each year that are serious enough to require hospital treatment ("Stairs, Ramps," 1974). As a consequence, stairs have consistently ranked at or near the top of the NEISS hazard priority rankings. Further, it is believed that there are close to 2 million temporarily or permanently disabling injuries attributable to stair accidents in the United States each year (McGuire, 1971; HUD, 1972), and conservative estimates attribute approximately 3,800 deaths to stair accidents each year (HUD, 1972). Again, using conservative estimates, the total annual cost of stair accidents in terms of compensation paid, workdays lost, and direct medical expenses exceeds $2,000,000,000 (Alessi & Brill, 1979).

In an attempt to identify ways to reduce the frequency and severity of residential stair accidents, the Consumer Product Safety Commission funded a major research project on stair, ramp, and landing hazards at the National Bureau of Standards (NBS) (Archea, Collins, & Stahl, 1979). In addition to an exhaustive review of previous research and existing standards pertaining to stair safety, NBS conducted a thorough examination of over 500 field reports of stair accidents which had been gathered by NEISS investigators and then conducted its own survey and inventory of stair use and stair quality in a stratified sample of residences in Milwaukee (Carson, Archea, Margulis, & Carson, 1978).

In addition, one of the most significant aspects of the work at NBS was the development of unobtrusive techniques for gathering and subsequently analyzing detailed videotape and film records of stair users in naturalistic settings (Archea et al., 1979; Templer, Mullet, & Archea, 1978). Records of over 32,000 stair users were obtained in various parts of the country, including approximately 120 who had noticeable missteps and almost 20 who had uncontrolled falls or accidents. From a detailed time-series analysis of these records, it was determined that visual perception is a major factor in successful stair use and that visual deceptions or distractions, which disrupt the typical visual scans associated with stair use, are a major factor in stair accidents (Archea et al., 1979).

Using a matched sample of stair users who did and did not have accidents recorded on the NBS videotapes, Templer et al. (1978), attempted to identify precipitating environmental and behavioral factors, such as handrail use, items carried, speed of movement, and type of clothing. The results of this analysis reinforced the importance of visual factors in stair accidents and shed additional light on the *importance of abrupt changes in stair conditions* (sudden distractions, changing light levels, etc.) in determining precisely where accidents would occur on each flight (Templer et al., 1978). Because of the richness of these videotape data, it became possible to pool incidence rates with those reported in the Milwaukee survey and by NEISS to give a first approximation of the frequency of missteps, accidents, injuries, and deaths on stairs as a function of use (Archea et al., 1979).

In earlier laboratory studies of energy expenditure and gait on stairs, Templer established an acceptable range of riser and tread dimensions for stairs, using subjective user comfort ratings and observed rates of missteps as the major criteria. In a related observational study of stair use in public settings, Templer also determined typical patterns of handrail use and channel selection on flights of stairs having different widths and configurations (Fitch, Templer, & Corcoran, 1974; Templer, 1974).

In 1982, Cohen and Compton reported the results of a study performed for the National Institute for Occupational Safety and Health (NIOSH). The study included detailed field investigation of work surface characteristics in the vicinity of 50 accidents in nine industrial and commercial settings. One of the major conclusions from this study was the important role that local variations in slip-resistance characteristics may play in work surface accidents—including stair accidents. This shed new light on the role of slip-resistance in pedestrian accidents and was consistent with some of the implications of the CPSC-NBS research, which had not been investigated in detail.

As a result of the studies by NBS (Archea et al., 1979), Templer (Templer, 1974; Templer et al., 1978), and Cohen and Compton (1982), it became apparent that making a successful transition from walking on a level landing to walking down a flight of stairs requires users to (a) look directly at the stair as they approach and step onto it and (b) cautiously "get the feel" of the treads while descending the first two or three steps. In effect, individuals must visually estimate the most appropriate initial placement of their foot on the first tread and then confirm the accuracy of both their estimate and their foot placement kinesthetically. Once assured that they are placing their feet within the limits imposed by the design and dimensions of the stair treads, users are free to attend to other portions of their visual surroundings as they continue their descent.

Within this framework, accidents were found to occur when this process was disrupted and the user abruptly encountered a nonconforming condition which he or she failed to anticipate from prior visual and kinesthetic cues. Such conditions could include changes in the level of slip-resistance or subtle variations in riser heights or tread depths. Visual deceptions built into the design of the stair and distractions that drew the user's attention away from the stair were found to be two of the leading causes of stair accidents (Archea, 1983; Archea et al., 1979; Carson et al., 1978; Templer et al., 1978).

The intent of the present study, which was funded by NIOSH, was to apply the type of analysis used in the NBS studies to the conditions encountered on industrial stairs. More specifically, the NIOSH study set out to identify design strategies for reducing the frequency of stair accidents at industrial and commercial sites.

METHOD

Selection of Stair Sites

The selection of sites for the study involved a focusing procedure to identify high-risk locations that (a) would be a better representation of the injury-causing potential of industrial stairs than could have been obtained by a random sample and (b) would enable a higher than average yield of incidents for each hour of videotape recorded. To do this, industries were selected that had a high incidence of stairway-related accidents.

Selection of specific industries. Based on an analysis of state workers' compensation records for New York and Ohio (Cohen, Templer, & Archea, 1985), industries were ranked with respect to the combined frequency and severity of stair-related injuries. These rankings are presented in the first two columns of Table 1.

In addition to ranking the frequency and severity of stair-related incidents, Table 1 reflects several other factors relevant to the conduct of detailed, behavioral observations. For example, most of the high-risk industries that were initially identified involved service functions or transitory conditions away from the employer's premises and, hence, were not controllable through structural design changes. Some examples included: police and fire protection, public health administration, building construction, trucking, membership organizations (social, fraternal, religious, etc.) and laundry services. Other industries initially identified from the New York and Ohio tapes were deemed to have been peculiar to those states. Examples included motion picture production and distribution in New York and foundries in Ohio.

Selection of specific establishments. The following criteria were then used to identify the specific establishments at which observations were to be made:

1. Selected industries should be broadly representative of the nine major Standard Industrial Classification (SIC) divisions (Office of Management and Budget [OMB], 1972).
2. Industries represented in the sample should involve a relatively high frequency and severity of stair-related accidents.
3. They should not include establishments that serve primarily as a homebase for workers predominantly involved in service or transitory functions remote from the employer's premises.
4. They should not include installations peculiar to a particular state; rather, they should represent types of establishments that can be found almost anywhere in the country.
5. Selected establishments should include generalized settings (e.g., offices, manufacturing areas, eating places, etc.) where a high volume of employee stair use is likely.

The task of selecting specific candidate sites began with a survey of professional organizations to identify a representative sample of the various industries within each of the SIC classifications. Two consumer organizations, five professional organizations, three governmental agencies, and nine industrial organizations were contacted by telephone in California, Georgia, and Ohio — the states in which the study was to be performed.

From these sources and the California, Georgia, and Ohio manufacturing directories, a number of candidate establishments were identified. The safety engineer, plant manager, and/or personnel director at each candidate site were contacted to solicit their potential interest in participating. Agreement was reached with 15 potential sites in California, 24 sites in Georgia, and 15 sites in Ohio. The number of candidate establishments selected in each industry category is shown in the third column of Table 1.

Selection of specific stairs. Each candidate site was visited by members of the research team, and selected characteristics of all candidate stair flights were recorded. Stair characteristics recorded included: location, the number of flights, flight lengths, effective stair widths, riser and tread dimensions, traffic density, percentage of use by employees, flooring materials, lighting, and potentials for unobtrusive videotape recording. In addition, 35-mm slides fully illustrating each stair and its setting were taken.

Preliminary field observations revealed that an average of 600 to 750 employee users could be expected on each flight during a typical work week. Based on an incidence rate of one per 175 uses (Archea et al., 1979), it was determined that a minimum of 30 flights would have to be observed in order to yield 100 to 125 incidents. The number of flights required for each industry classification was then adjusted in proportion to the frequency/severity index for that industry, as shown in the second column of Table 1. The number of flights observed in each category is shown in the last column of Table 1.

The final selection of flights was based on (a) the widest range of dimensional and configurational characteristics, (b) the highest volume of employee use, (c) potential for good

TABLE 1
INDUSTRIES RANKED ACCORDING TO THE COMBINED FREQUENCY AND SEVERITY OF STAIRWAY-RELATED INJURIES

INDUSTRY RANKING	FREQUENCY-SEVERITY INDEX	NUMBER OF CANDIDATE ESTABLISHMENTS	NUMBER OF FLIGHTS OBSERVED
Miscellaneous manufacturing	6.437	13	10
Administration of public health	4.262	[a]	[a]
Police and fire protection	4.022	[a]	[a]
Membership organizations	2.967	[a]	[a]
Local and long distance trucking	1.997	[a]	[a]
Blast furnaces and foundries	1.964	[a]	[a]
Motion picture distribution	1.712	[a]	[a]
Hotels and motels	1.688	3	2
Educational services	1.659	7	3
Local and state government	1.617	7	3
Agricultural products	1.611	[a]	[a]
Food and kindred products	1.526	11	4
Industrial chemicals	1.390	[a]	[a]
Apparel stores	1.250	2	2
Transportation services	1.102	[a]	[a]
Laundry services	1.074	[a]	[a]
Air and water management	1.028	[a]	[a]
Building construction	.973	[a]	[a]
Medical offices	.964	[a]	[a]
Eating and drinking places	.889	5	5
Miscellaneous retail	.889	6	2

[a]Industries dropped from consideration for reasons cited in the text.

camera angles, and (d) proportional representation within each industry category. Note that several of the candidate staircases had composite layouts. This means that they were composed of several straight flights coupled to landings in various configurations. In such cases, individual sections were selected as if they were independent flights with different settings.

Videotape Methodology

The data collection phase involved the recording of the characteristics and actions of people using each of the 31 flights of stairs that had been selected by the procedures presented above. After the final selection of locations had been completed, a notice was posted to inform employees of the nature and purpose of the study. Employees were given the option to not participate in the study by informing the field researcher of his or her desire not to be taped. Although the vast majority of users videotaped were employees of the company, occasional visitors to the company may have been videotaped as well.

It was originally intended that Super-8 movie cameras would be utilized for the data collection. After a thorough examination of the available technology, however, videotape was chosen as a superior collection instrument for the following reasons:

1. Recordings could continue for up to 2 hours without reloading— as compared to 10 minutes for film.
2. Recordings could be instantly replayed to ensure that clear images had been obtained.
3. Recorded information could be edited and transferred electronically to master tapes as required for analysis purposes.

Setting up recording equipment. The recording equipment was located where it would be as unobtrusive as possible, yet would provide a clear view of the users from head to foot, as they negotiated each flight. Two cameras were used for most flights. From previous work, it was found that the top and the bottom of flights were the locations for a disproportionately high percentage of incidents (Templer et al., 1978). Therefore, on long flights the cameras were focused on these points.

Recording time. Because it was necessary to consider the possibility that stair incidents occur more frequently at certain times of the day, or on certain days of the week, the videotape recordings were made throughout the workday, 5 days a week. Every stair use was recorded and analyzed for the duration of the study. Data were collected between 24 and 40 hours at each stair site.

Physical measures. As stated earlier, all of the physical conditions of the stair were recorded in detail. Any changes in environmental condition during the recording process were fully recorded.

ANALYSIS

All tapes were studied by trained coders to identify all conceivable stair incidents. Any abnormal behavior associated with the use of the stair was noted. This included such behaviors as a misstep or slip, bumping into another person on the stair, suddenly reaching for the handrail, and any form of hesitation or disruption in the subject's forward progress.

Thirty percent of the tapes were rechecked to ensure reliability. A total of 516 potential incidents were identified. These were then reviewed a second time to identify bona fide accidents and missteps. Only those incidents in which there was a clear misstep, loss of balance, or apparent disruption of the user's intended pattern of movement were selected. A total of 98 undisputed critical incidents were selected for the final analysis.

Matched Sample

One hypothesis of the study was that some types of behavior on stairs, or the physical characteristics of some users might have caused an incident. To test this, the personal and behavioral characteristics of the people involved in incidents on the stairs (the incident sample) were compared to the characteristics of a matching group of stair users who did not have incidents (the nonincident sample). The nonincident sample was formed by selecting the third person traveling in the same direction prior to each person who had an incident on a given flight.

This procedure ensured that the nonincident sample duplicated closely the circumstances of the incident sample in terms of the time of day, the day of the week, the stairway used, ambient environmental conditions, and the general presence of other users. It also assured that the behavior of each incident victim and his or her nonincident match would be independent of each other. The resulting groups provided a plausible basis for establishing valid relationships between specific personal or behavioral characteristics of the users and the occurrence of stair accidents, missteps, or other critical incidents.

Observer Training and Reliability

Coder training involved approximately 7 hours of instruction and trial data takeoffs. Much of the training was directed toward assuring a high level of observational reliability. (The reliability was rechecked periodically during the data processing phase.) During this period, the observers were familiarized with the variables to be identified, the levels of each variable, videotape observation procedures, and the data recording procedures. From previous research it was clear that the degree of coding precision decreased as the amount of observer judgment increased (Templer et al., 1978). Much of the training period concentrated on improving the precision of the observers' judgmental decisions.

Coding

One hundred twenty-three independent (or predictor) variables were analyzed in this study. Each was chosen for its possible influence on stair accidents. Many of these had been shown in previous studies to correlate significantly with accidents (Archea et al., 1979; Carson et al., 1978; Templer et al., 1978). These variables fell into three categories:

1. *Environmental conditions*—These included riser height, tread depth, nosing projection, wash (the slope of the tread toward the nosing), illumination characteristics, stair width, handrail characteristics, orientation factors (such as the presence of rich views to the user's right or left), etc. All of the environmental variables were based upon precise measurements or observations made in the field.
2. *User characteristics*—These included age, sex, race, body type, obvious handicaps, clothing, items carried, group ecology (such as being alone or with one or more others), etc. All of these user characteristics were coded from the videotape records obtained in the field.
3. *Behavioral characteristics of the user*—These included the occurrence of incidents, direction of movement, speed, route taken, degree of attention paid to others, handrail use, traffic density, gait, direction of gaze, etc. All of these behavioral characteristics were coded from the videotapes.

Statistical Analysis

Two major statistical techniques were employed, discriminant analysis and multiple regression, using the *Statistical Package for the Social Sciences* (SPSS). Where the dependent variables of interest were categorical, such as incident versus nonincident, the discriminant analysis was employed. Multiple regression analyses were used to determine the relative impact of the independent environmental variables (e.g., handrail height, tread depth, etc.) and behavioral variables (e.g., percent of foot on the tread, direction of gaze, etc.) on quantitative dependent measures, such as incidence rate per flight or per tread.

RESULTS

Discriminant Analysis

To identify the factors that discriminated between an incident occurring and no incident occurring, incidents were assigned to one group, while nonincidents were assigned to another. The issue then became: Which of the many descriptors recorded for the stairs, the users, and their behavior best discriminated between the incident and nonincident groups?

The discriminant analysis in this case was essentially a factor analysis with factor loadings on a single factor. The discriminant weightings for the variables chosen reflected the least-squares maximization of the ratio of between-group variance to within-group variance. In other words, variables were chosen and weighted to maximize the discrimination between the incident and nonincident groups.

The discriminant analysis for the characteristics of the stair users and their behavior revealed that the factors that best distinguished the incident group from the nonincident group were: (a) The incident group tended to be those whose movement was impeded by others and those who were older and (b) The nonincident group tended to be those who were wearing glasses and those who were very large or heavy.

The standardized equation generated for this analysis was:

$$y = .87(B6B) - .62(B9A) - .46(B10B) + .43(C16B)$$

where B6B represents the subject's age, B9A the subject's weight rating, B10B the subject's use of glasses, and C16B the rating for the impeded movement caused by others.

A discriminant analysis was also performed for the characteristics of the stair treads involved in the incidents compared with stair treads on which no incidents occurred. The analysis revealed that the factors which most distinguished the incident treads from the nonincident treads were: (a) The incident treads tended to be those with larger nosing projections and those with a greater number of rated orientation changes from the previous treads and (b) the nonincident treads tended to be associated with the presence of views ahead of the subject.

The standardized equation generated for this analysis was:

$$y = .34(A6) - .73(A31A) + .42(A60)$$

where A6 represented the nosing projection, A31A the presence of views ahead of the subject, and A60 the number of rated orientation changes from the previous tread.

Multiple Regression

The regression analyses generated equations that represented the relative contributions of each of the independent variables in predicting variability in the dependent measures. Some of the independent measures used in the regression analyses were categorical variables, such as the tread materials or the direction of the user's gaze. Such variables were dummy coded using a binary scale (0, 1).

A total of 98 incidents were recorded on 31 flights of stairs. Since there were 72 environmental conditions (A variables), it was not possible to consider all of these in a step-wise multiple regression with only 31 observations of the dependent variable (the incidence rate of each flight or tread), so a focusing procedure was used. Simple correlations between the stair incidence rates and each of the A variables were examined and those that were statistically significant (at the .05 level or higher) were utilized as candidates in the stepwise multiple regression.

Incidence rates per flight. The incidence rate per flight was determined by dividing the total number of incidents recorded on each flight by the total number of people who had been recorded as users of that flight. Separate analyses were done with the data for ascent and descent combined, for ascent only, and for descent only. The independent variables used in this analysis were the means of the separate measurements made for each environmental attribute on every riser or tread within the flight.

With the data for *ascent and descent combined*, higher incidence rates were found on flights with a greater mean wash ($r = .407$, $df = 29$, $p < .05$), higher mean effective riser height ($r = .385$, $df = 29$, $p < .05$), and less mean effective tread depth ($r = .358$, $df = 29$, $p < .05$). For the 31 flights in the sample, the mean wash was 3/16 in. (0.5 cm), the mean effective riser height was 7 1/8 in. (18 cm), and the mean effective tread depth was 10 3/16 in. (26 cm). Based on these data for flights as a whole, it would appear that mean washes and mean effective riser heights that exceed 3/16 in. (0.5 cm) and 7 1/8 in. (18 cm), respectively, and mean effective tread depths that are less than 10 3/16 in. (26 cm) would be associated with higher than average incidence rates.

When the data for ascent were separated from those for descent, it was found that the influence of effective tread depth and effective riser height was greatest in ascent. For *ascent*, the correlation between incidence rates and effective tread depth was $-.430$ ($df = 29$, $p < .01$), while that for effective riser height was $.327$ ($df = 29$, $p < .05$). This means that higher incidence rates in ascent were associated with effective treads that were narrower than 10 3/16 in. (26 cm) and with risers that were higher than 7 1/8 in. (18 cm) — when incidence rate per flight was used as the criterion measure.

For *descent*, no statistically significant correlations were found between incidence rates per flight and effective riser or tread dimensions. Higher incidence rates in descent were found to be associated with greater mean nosing projections, however ($r = .338$, $df = 29$, $p < .05$). Since the mean nosing projection on the 31 flights in the sample was 11/16 in. (1.8 cm), it would appear that nosing projections that exceeded this dimension were associated with higher than average incidence rates.

Although each of the factors cited above was found to be significantly associated with incidence rates per flight, none of these contributing factors was found to be significant in a regression equation when the incidence rates in ascent and descent were considered together or separately.

Incidence rates per tread. Since more than one incident was recorded for several of the treads on some of the flights, it was possible to establish a rate for each tread on which one or more incidents had occurred by dividing the number of incidents observed by the total number of users per flight. The following three rates are defined:

1. *Incident Tread Ascent Incidence Rate (ITAIR).* For those treads on which an incident occurred when the person was ascending, the ITAIR is the ratio of the number of ascending incidents on that tread to the number of observed ascending users of that tread.
2. *Incident Tread Descent Incidence Rate (ITDIR).* For those treads on which an incident occurred when the person was descending, the ITDIR is the ratio of the number of descending incidents on that tread to the number of observed descending users of that tread.
3. *Incident Tread Combined Incidence Rate (ITCIR).* For those treads on which an incident occurred when the person was either descending or ascending, the ITCIR is the ratio of the number of observed incidents on that tread to the number of observed users of that tread.

Table 2 shows the attributes of the treads that were significantly correlated with ITCIR. A plus sign (+) indicates that the attribute was associated with a higher incidence rate, while a minus sign (−) indicates that it was associated with a lower incidence rate. Table 2 includes the findings for the incident tread (for which the ITCIR was calculated), as well as for the three treads traversed by the user prior to reaching the incident tread.

From Table 2 it can be seen that the steps with higher ITCIRs were characterized by: (a) less effective tread depth ($r = .467$, $df = 48$, $p < .01$); (b) higher effective riser height ($r = .432$, $df = 52$, $p < .01$); (c) less handrail-to-handrail width ($r = .328$, $df = 43$, $p < .05$); (d) linoleum or tile treads ($r = .291$, $df = 57$, $p < .05$); and (e) being visually enclosed on both sides ($r = -.272$, $df = 57$, $p < .05$). In this analysis, the mean effective tread depth was 9 15/16 in. (25.3 cm), the mean effective riser height was 7 3/16 in. (18.3 cm), and the mean handrail-to-handrail width was 44 13/16 in. (102.8 cm). The treads with lower ITCIRs were of concrete or stone material ($r = .526$, $df = 57$, $p < .01$) and had rich views open to one side ($r = -.364$, $df = 57$, $p < .01$).

The concrete or stone materials and rich views open to one side, which were associated with treads having lower ITCIRs, were also found to be characteristic of each of the three treads prior to the incident tread. Similarly, linoleum or tile materials were also associated with the three treads prior to the incident treads with higher ITCIRs. Less effective tread depth and higher effective risers were also characteristic of the treads immediately prior to the ones having higher ITCIRs.

The multiple regression equation generated for these observations was:

$$y = -.25(A7_1) + .32(A7_3) + .95(A24C_0) - .64$$

where y was ITCIR, $A7_1$ was the depth of the tread immediately prior to the incident tread ($M = 9$ 15/16 in. [25.3 cm]), $A7_3$ was the depth of the third tread prior to the incident tread ($M = 9$ 15/16 in. [25.3 cm]), and $A24C_0$ was the presence of stone or concrete materials on the incident tread itself.

The data for incidents occurring in descent were then separated from the data for the incidents occurring in ascent. Tables 3 and 4 show the stair attributes that were found to be significantly associated with higher or lower incidence rates in descent and ascent, respectively. Note that Tables 3 and 4 only include the incident tread (T_0) and the tread immediately prior to the incident tread (T_1). This is because the number of incidents occurring at the top or the bottom of a flight was so great that there were not a sufficient number of treads prior to T_1 to generate an adequate number of cases to be considered in the regression analysis.

TABLE 2
TREAD ATTRIBUTES CORRELATED WITH ITCIR

ATTRIBUTE	INCIDENT TREAD	1ST PRIOR TREAD	2ND PRIOR TREAD	3RD PRIOR TREAD
Concrete or stone treads	−	−	−	−
Less effective tread depth	+	+		+
Open with a rich view on one side	−	−	−	−
Linoleum or tile treads	+	+	+	+
Higher effective riser height	+	+	+	+
Enclosed on both sides	+		+	
Less handrail-to-handrail width	+			
Handrail present on left side descending				+

Note. − + = factor associated with higher ITCIR; − = factor associated with lower ITCIR.

When the *descent* incidents were considered alone, it was found that higher effective riser heights ($r = .581$, $df = 25$, $p < .01$) and the presence of linoleum or tile treads ($r = .490$, $df = 30$, $p < .01$) were more strongly associated with higher ITDIRs, and that the presence of concrete or stone treads ($r = -.633$, $df = 30$, $p < .01$) was more strongly associated with lower ITDIRs. For these data, the mean effective riser height was 6 15/16 in. (17.7 cm).

By contrast when *ascent* was considered alone, less effective tread depth ($r = -.584$, $df = 33$, $p < .01$) was more strongly associated with higher ITAIRs, while the presence of rich views open to one side ($r = .491$, $df = 37$, $p < .01$) was more strongly associated with lower ITAIRs. In this case the mean effective tread depth was 9 13/16 in. (25 cm).

The multiple regression equation generated for descent was:

$$y = .16(A4_1) - .83$$

where y was ITDIRs and $A4_1$ was effective height of the riser for the tread immediately prior to the incident tread ($M = 6$ 15/16 in. [17.7 cm]).

The multiple regression equation generated for ascent was:

$$y = -.16(A7_0) - .18(A30C_0) + .19$$

where y was ITAIR, $A7_0$ was the effective depth of the incident tread ($M = 9$ 13/16 in. [25 cm]), and $A30C_0$ was the absence of a rich view open to one side on the incident tread.

Other factors found to have been significantly associated with higher incidence rates in *ascent* (ITAIR) but not selected in the multiple regression were the presence of visual enclosures on both sides of the flight ($r = -.461$, $df = 37$, $p < .01$) and higher effective riser heights ($r = .377$, $df = 35$, $p < .05$). The mean effective riser height for ascending incident treads was 7 5/16 in. (18.5 cm), which is 3/8 in. (0.9 cm) higher than that found for descent. Note that while higher effective riser heights were significantly associated with higher ITAIRs and ITDIRs, the correlation was much stronger for ITDIR.

Additional factors found to have been significantly associated with higher ITDIRs were greater visibility of the tread edges

TABLE 3
TREAD ATTRIBUTES CORRELATED WITH ITDIR

ATTRIBUTE	INCIDENT TREAD	1ST PRIOR TREAD	2ND PRIOR TREAD	3RD PRIOR TREAD
Higher effective riser height	+	+		
Concrete or stone treads	−	−		
Linoleum or tile treads	+	+		
Less tread wash	+	+		
Greater visibility of tread edges from above	+	+		
Open with a rich view on one side		−		

Note. − + = factor associated with higher ITDIR; − = factor associated with lower ITDIR.

TABLE 4
TREAD ATTRIBUTES CORRELATED WITH ITAIR

ATTRIBUTE	INCIDENT TREAD	1ST PRIOR TREAD	2ND PRIOR TREAD	3RD PRIOR TREAD
Less effective tread depth	+	+		
Open with a rich view on one side	–	–		
Enclosed on both sides	+	+		
Higher effective riser height	+	+		
Concrete or stone treads	–	–		
Linoleum or tile treads		+		

Note. – + = factor associated with higher ITAIR; – = factor associated with lower ITAIR.

when viewed from above ($r = .440$, $df = 28$, $p < .05$) and less wash on the treads ($r = -.413$, $df = 24$, $p < .05$).

Overall, it was found that higher ITDIRs were associated with higher effective riser heights (especially on the tread prior to the incident tread) and the nature of the tread materials. Since measured slip-resistance was not found to have been a significant factor in this study, the higher ITDIRs associated with tile or linoleum treads, and the lower ITDIRs associated with concrete or stone treads, suggest that material characteristics other than slip-resistance may have played an important role in the incidents associated with descent. Previous research (Archea et al., 1979) suggests that appearance might be a mediating factor. The findings reported in the previous paragraph on the effects of visibility of the tread edges confound this interpretation, however.

In ascent, the higher ITAIRs were associated primarily with less effective depth on the incident tread and on the tread immediately prior to it and associated to a much lesser extent with higher effective riser heights on both of these treads and with the visual context on either side of the flight.

Since higher ITAIRs were associated with total visual enclosure on both sides of the flight and lower rates were associated with rich views open on one side, it does not appear that visual distractions of the type previously reported (Archea, 1983; Archea et al., 1979; Carson et al., 1978; Templer et al., 1978) could account for these findings. It seems plausible, however, that the amount of caution exercised by the users might have been a mediating factor. According to this scenario, users in fully enclosed stairways may have been less cautious in their use of the stair than those whose visual attention was diverted away from the stair itself by compelling view off to one side. The behavioral implications of this possibility will be considered in the next section.

Behavioral factors. The behavioral factors found to have been significantly associated with ITCIRs are shown in Table 5. Here, all of the behaviors found to have been associated with higher or lower ITCIRs on the incident tread are presented. The four columns on the right part of Table 5 indicate the tread on which the behavior occurred.

With the data for *ascent and descent combined*, the ITCIRs were found to have been associated with the following behaviors on the incident tread: (a) having less of the foot on the tread ($r = -.256$, $df = 79$, $p < .05$); (b) looking to the right or left ($r = .254$, $df = 96$, $p < .05$); (c) not having been in the right-hand third of the flight ($r = -.233$, $df = 96$, $p < .05$); (d) not having their foot twisted to the left ($r = -.177$, $df = 96$, $p < .05$); and (e) not watching other persons ($r = -.177$, $df = 96$, $p < .05$). Having less of the foot on each tread was consistently found to be associated with higher ITCIRs for each of the three treads prior to the incident tread as well. The same was true for not being in the right-hand third of the flight and, except for the second tread preceding the incident tread, for looking to the right or the left.

Higher ITCIRs were also found to be associated with the following behaviors which occurred in one or more of the treads preceding the one on which they occurred: (a) using the handrail to pull up, (b) walking in the center of the flight, (c) having no hand on

TABLE 5
BEHAVIORAL FACTORS CORRELATED WITH ITCIR

ACTION	INCIDENT TREAD	1ST PRIOR TREAD	2ND PRIOR TREAD	3RD PRIOR TREAD
Less of the foot on the tread	+	+	+	+
In right-hand third of the flight	–	–	–	–
Looking to the right or left	+	+		+
Using the handrail to pull up		+	+	+
No hands on either rail			+	+
Foot twisted slightly to the left	–			
Watching other persons	–			
In center third of the flight		+		
Looking straight ahead			+	
Looking down				–

Note. — + = factor associated with higher ITCIR; – = factor associated with lower ITCIR.

either rail, (d) looking to the right or left, and (e) not looking down. Of these factors, only the use of the handrail to pull up on the first through third treads prior to the incident tread and the nonuse of the handrail on the second and third prior treads appear to constitute behavioral patterns that might be related to stair accidents.

The multiple regression equation generated for ascent and descent combined was:

$$y = -.31(C9_1) + .24$$

where y was ITCIR and $C9_1$ was the proportion of the foot placed on the tread prior to the incident tread.

When the behavioral patterns for descending subjects were separated from those for ascending subjects it was found that the subjects' behavior was much more closely associated with ITDIR than ITAIR. The behavioral factors found to be significantly associated with higher or lower ITDIR are shown in Table 6. It includes behaviors that occurred on the incident tread as well as on the three treads prior to the incident tread. Note that so few behavioral factors were significantly related to ITAIR that no comparable table has been included for those findings.

In *descent*, using the handrail for guidance and balance was directly associated with higher ITDIRs ($r = .590$, $df = 30$, $p < .01$). Having the foot twisted slightly to the left ($r = -.424$, $df = 30$, $p < .01$), looking straight ahead ($r = -.350$, $df = 30$, $p < .05$), and being in the right-hand third of the flight ($r = -.347$, $df = 30$, $p < .05$) were all significantly associated with lower ITDIRs on the incident tread. The ITDIR was also significantly associated with these same four behaviors occurring on the tread immediately prior to the incident tread. Using the handrail for guidance

TABLE 6
BEHAVIORAL FACTORS CORRELATED WITH ITDIR

ACTION	INCIDENT TREAD	1ST PRIOR TREAD	2ND PRIOR TREAD	3RD PRIOR TREAD
Use of handrail for guidance and balance	+	+	+	+
In right-hand third of the flight	–	–	–	–
Less of the foot on the tread		+	+	+
Foot twisted slightly to the left	–	–		
Looking straight ahead	–	–		
No hands on either rail		+	+	+
Looking up			+	
Looking to the right or left				+

Note. — + = factor associated with higher ITDIR; – = factor associated with lower ITDIR.

and balance and being in the right-hand third of the flight on the second and third treads prior to the incident tread were also significantly associated with ITDIR.

Having less of the foot on the tread and no hands on either rail were significantly associated with higher ITDIRs for the first through third treads prior to the incident tread in descent. Looking up on the second prior tread and looking to the right or left on the third prior tread were also significantly associated with higher ITDIRs.

The multiple regression equation generated for descent alone was:

$$y = -.78\ (C9_1) + .52$$

where y was ITDIR and $C9_1$ was the proportion of the foot placed on the tread prior to the incident tread. This means that having less of the foot placed on the tread prior to the incident tread was the major behavioral factor associated with the incidents recorded in this study. Further consideration of the uses of the handrails and of where the subjects were looking will be included in the discussion section.

Finally, in *ascent*, watching other people while on the incident tread ($r = -.300$, $df = 37$, $p < .05$), not looking straight ahead on the second prior tread, and being in the right-hand third of the flight, having hands on both rails, or not using the handrail for physical support on the third prior tread were all found to be significantly related to lower ITAIR. None of these factors, however, appears to contribute to a consistent pattern of stair incidents, and none was selected in the multiple regression analysis.

DISCUSSION

In general, four major factors were found to be associated with incidence rates in the present study. These factors were: (a) riser and tread dimensions, (b) tread materials, (c) visual surroundings, and (d) handrail use. Each of these will be discussed in turn.

Riser and Tread Dimensions

High risers and narrow treads were the design features most consistently found to be associated with incidents on industrial stairs. For the combined ascent and descent data, narrow treads on the first and third treads prior to the ones on which incidents occurred were found to be significantly associated with those incidents. For the ascent data alone, narrow treads at the point at which the incident occurred were also found to be significantly associated with those incidents. For the descent data alone, higher risers on the treads prior to the ones on which the incidents occurred were found to be significantly associated with those incidents.

For ascent, it would appear that narrow treads tend to cause understepping at the point of incident, and this was the major design factor associated with stair accidents.

For descent, it would appear that overstepping the tread prior to the incident tread was the major factor associated with stair incidents. This conclusion is supported by the finding that the users had less of their foot on the tread prior to the incident tread in descent—which is the equivalent of overstepping. Since this tread was accompanied by higher risers, in descent, it would appear that much of this overstepping could be attributed to the increased forward trajectory of the descending foot as a result of having slightly farther to fall from the higher tread above. The finding that having the foot twisted slightly to the left on the incident tread and on the tread prior to it was associated with lower incidence rates suggests that those people who successfully compensated for the effects of this higher riser had fewer incidents.

The critical dimensions associated with incidents on stairs were determined by using the means and standard deviations of the riser and tread dimensions found to be significantly correlated with incidence rates. Note that in this study all riser and tread dimensions found to be significantly associated with incidence rates were the *effective* dimensions rather than the simple measured dimensions. This means that for riser height, the critical dimension was the height of the face of the riser plus the wash of the tread below. For tread depth, the critical effective dimension was the measured depth of the tread less the nosing overhang for the tread above.

Using a composite of the means per flight and per tread, higher than average incidence rates were found when the effective riser heights exceeded 7 1/8 in. (18 cm) and when the effective tread depths were less than 10

3/16 in. (26 cm). Using the standard deviations to identify dimensions more closely associated with lower incidence rates, it was found that the safest stairs would have a maximum effective riser height of 6 in. (15 cm) and a minimum effective tread depth of 11 in. (27 cm).

Although the former pair of dimensions may be appropriate for reducing the number of incidents on industrial stairs, the latter pair would be preferable for providing a genuinely safe stair. These dimensions are quite consistent with those reported by Templer (Fitch et al., 1974; Templer, 1974).

Tread Materials

Throughout the analysis of tread-specific incidence rates, higher incidence rates per tread were consistently associated with linoleum or tile treads, while lower rates were consistently associated with concrete or stone treads. This was true for the incident tread and all three of the immediately preceding treads when the data for ascent and descent were combined. When the data for ascent and descent were treated separately, the material factor appeared to be much more critical in descent.

Since measured slip-resistance was not found to have been significantly associated with the incidents recorded in this study, it would appear that a more complex relationship might have operated with regard to tread materials. For example, it was found that higher incidence rates in descent were significantly associated with having had less of the foot on the tread prior to the incident tread and with higher risers at this same location. Combining these findings with the findings on tread materials suggest that the effects of materials may have been related to overstepping, especially in descent.

According to this scenario, as stair users overstepped the tread immediately prior to the incident tread, and onto the incident tread itself, they placed their foot closer than normal to the nosing and thus brought maximum horizontal forces to bear on a minimal surface area. In this case, the rough concrete or stone would be in a better position to retard further forward movement toward or over the nosing than the much smoother surface presented by tile or linoleum. Such interactions between surface materials and foot placement have been posited by others (Archea et al., 1979; Carson et al., 1978; Harper, Warlow, & Clarke, 1967).

The possibility that differences in the appearances of these materials may have had a mediating effect on incidence rates is also consistent with earlier findings (Archea et al., 1979; Carson et al., 1979; Templer et al., 1978). The data from the present study, however, do not permit the resolution of either of these alternative explanations of the effect of tread materials.

Visual Surroundings

The discriminant analysis indicated that the incident treads tended to be those with no views straight ahead and higher numbers of orientation changes from the previous treads. Several other findings pertaining to the availability of views to the user's right or left and to the directions in which they were actually looking, however, intially appear to give contradictory results. For example, in the tread-specific analysis, when the data for ascent and descent were combined, lower incidence rates were found where rich views were available to the right or left, while higher rates were found when the users actually looked to their right or left. Higher rates were also found when the views to the right or left were obscured by solid walls. A similar pattern was found when the data for ascent were considered alone. In descent, lower rates per tread were found when the users were looking straight ahead, while higher rates were found when they looked away from the stairs (up or to their right or left).

Handrail Use

It was consistently found that lower incidence rates per tread were found when the user was in the right-hand third of the flight, but that higher rates were found when they actually used the handrail to pull themselves up in ascent or for guidance and balance in descent. The rate was also higher when they failed to use the handrail at all in descent for the first through third treads prior to the incident tread.

Again, it would appear that the user's perception of risk and use of caution may have been a factor in handrail use. Those who needed to use the handrail to pull themselves up may initially have been more vulnerable and thus had more incidents. This is consistent with the higher incidence rate for older subjects found in the discriminant analysis. On the other hand, those who merely used the handrail for guidance and balance may have been lulled into a sense of security that masked some of the risks involved in descending stairs. In a sense, those who stayed on the right-hand side of the flight were not too dependent on the handrail, but kept themselves in the best position to use it if necessary. This interpretation is largely consistent with earlier findings (Carson et al., 1978) that, comparing residential stairways with and without handrails, proportionally more missteps occurred on residential stairs with handrails, but more serious injuries occurred on flights without handrails.

Again the data from this study do not resolve the role played by the handrail in stair accidents. Since this issue relates more to how the stair is used, however, its ultimate resolution may be more of a consumer education issue than a design or maintenance problem.

CONCLUSIONS

In general it was found that several design factors were related to higher incidence rates on industrial and commercial stairs. These included risers in excess of 6 to 7 in. (15 to 18 cm) in effective height, treads of less than 10 to 11 in. (25 to 27 cm) in effective depth, and tile or linoleum tread materials. Concrete or stone treads and the presence of visual distractions to the side of the user's path of travel were found to be associated with lower incidence rates. In the latter case, it was further suggested that, while the presence of a visual distraction may increase the degree of caution exercised by the user, those who were actually distracted were likely to experience a greater number of incidents. This issue of the interaction between the appearance of a hazard and the user's attempts to compensate for the consequences of that hazard should be the focus of future research.

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