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Accidental Deaths Caused by Electricity in Sweden, 1975–2000

ABSTRACT: This study analyzes accidental fatalities caused by electricity—at work and during leisure time—to evaluate risk factors, the role of alcohol, and to identify possible preventive strategies. In Sweden, data on fatalities by electrocution from 1975 through 2000 were collected from the National Cause-of-Death Register. Additional cases were found in the archives of The Swedish National Electrical Safety Board. Suicides and deaths by lightning were excluded. Two hundred and eighty-five deaths were found, including occupational ($n = 132$), leisure time ($n = 151$), and unknown ($n = 2$). Most deaths were caused by aerial power lines, and the most common place for an electrical injury was a railway area or residential property. Postmortem blood from 20% ($n = 47$) of the tested cases was found positive for alcohol, and these persons were killed mainly during leisure time. During the study period, the overall incidence of electricity-related fatalities has decreased, in spite of increased use of electricity. This indicates that safety improvements have been successful.

KEYWORDS: forensic science, electrocution, occupational, leisure time, alcohol

Accidental electrocution is an uncommon cause of death in Sweden. According to official statistics, all accidental deaths during the last quarter of the last century ranged between 3929 and 2422 persons annually. Deaths due to electricity represented 0.36% (range 0.15–0.52) of these (1,2).

The literature on fatalities caused by electricity is scarce, including a limited number of studies analyzing occupational electrocutions (3–7) and *all* accidental deaths caused by electricity (8–10). Other studies have reported on occupational fatalities, of which electrocution cases represent only a small part (11–14).

This descriptive study closely analyzes fatalities caused by electricity in Sweden, both occupational and leisure time, in order to uncover risk factors such as alcohol and to identify possible preventive strategies.

Materials and Methods

Data on all fatalities in Sweden due to accidental electrocution, i.e. ICD-codes E925 and W85–87 (15,16), from 1975 through 2000 were collected from the National Cause-of-Death Register. In all but 33 of these cases, we scrutinized police and autopsy records, including toxicological analyses. Reports or comments from the Swedish National Electrical Safety Board or other appropriate authority were found in all but 14 cases.

"Electrocution" as the cause of death was defined as any combination of electric shock, burn injuries caused by arc light, and injuries by caused by falls from a height due to electric shock. Deaths found to be caused by lightning or as a result of suicide were excluded. The Swedish National Electrical Safety Board (Elsäkerhetsverket) keeps its own statistics, which contained an additional 13 fatalities not detected through the National Cause-of-Death Register. These 13 cases were also included in the study.

The Nordic Classification of Occupations (17) was used to allocate the cases according to occupation. The term "electricians" included electronics engineers and technicians, electrical engineers and technicians, electric linesmen, and operators of stationary engines and related equipment.

The injury events were also classified according to the electrical voltage involved. High voltage was defined as 1000 V or more, and low voltage as less than 1000 V.

The authors estimated who had been at fault, causing the fatal event, by studying the collected investigation reports and comments.

Statistical analyses regarding trends were performed using Poisson regression.

Results

General

A total of 285 cases were found: 269 (94%) were men and 16 women. Of these, 151 fatalities occurred during leisure time, and 132 in an occupational situation. In two cases, it could not be determined whether the event had occurred during leisure or occupational time. The mean age was 38 years, the median age was 35 years, and the range was 10 months–92 years.

Comparing the material in 5-year periods, there was a significant ($p < 0.001$) decreasing trend (Fig. 1). Deaths due to electricity decreased from 17.4 to 5.8 per year, while the total incidence of *all* accidental deaths decreased from 3823.8 to 2510.5 deaths per year (1,2). The ratio between occupational and leisure time deaths can be seen in Fig. 2. When comparing the first 5 years of the study with the last 6 years, deaths caused by high voltage decreased by 73% ($p < 0.001$) and low voltage decreased by 55% ($p < 0.001$).

Analyses of blood alcohol were performed in 231 cases (81%) and of urine in 218. Forty-seven cases (20%) tested positive for alcohol in blood (Fig. 3) and five for alcohol in urine but negative in blood. During the first 5 years of the study, 20% of those tested for alcohol in blood were found positive, and 19% during the last

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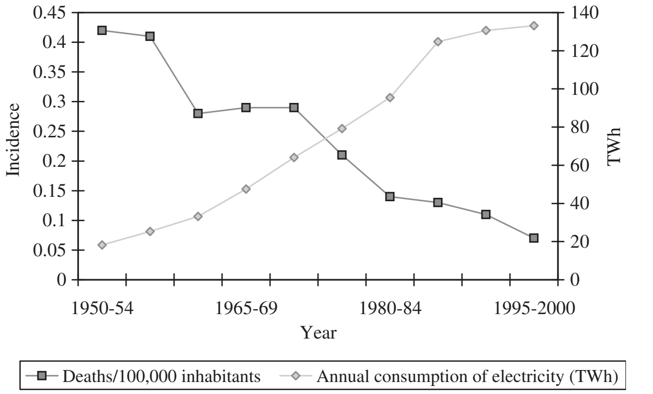

FIG. 1—*Incidence of fatalities due to electricity (1950–1974 (1,18,19); 1975–2000 present investigation) and the national consumption of electricity (1,2,19) in Sweden, 1950–2000. In relation to the Swedish population, this equals to a decrease of fatalities from 0.42 to 0.07/100,000 inhabitants ($p<0.001$) (1,2,19).*

6 years (Table 1). Screening for illegal drugs was performed in 135 cases; two were positive.

The most common place of the fatal event was a railway site ($n=64$; 22%), followed by residential areas indoors and substations (Table 2).

More than half the number ($n=155$; 54%) of the fatalities occurred after contact with low-voltage current. One hundred and thirteen (40%) died after contact with aerial power lines, and the distributions between occupational and leisure time among these were 54 (48%) and 59 (52%), respectively (Table 3). Defective equipment caused 54 (19%) deaths (Fig. 4). Circumstances surrounding the deaths of children, adolescents, and those with positive blood alcohol are further described in Tables 4 and 5.

The most frequent mechanism of fatal injury was cardiac arrhythmia due to electric shock ($n=226$; 79%; Fig. 5). Twenty-seven victims died from burns involving multiple parts of the body, all but one after contact with high-voltage current.

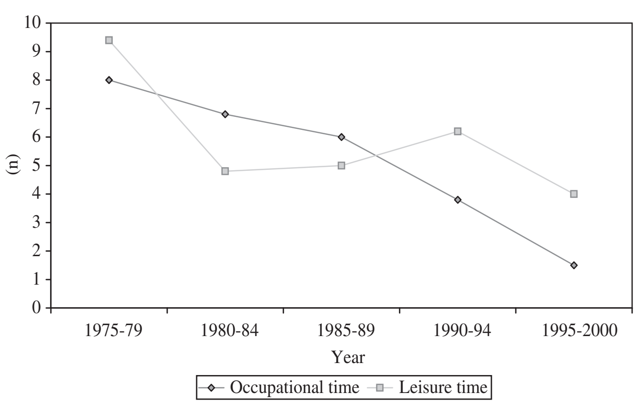

FIG. 2—*Mean annual number of deaths during occupational time and leisure time.*

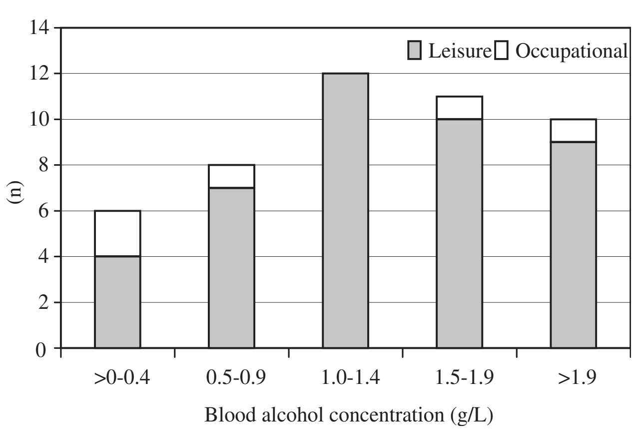

FIG. 3—*Number of victims in fatal accidental injury events due to electricity, testing positive for alcohol in blood ($n=47$).*

TABLE 1—*Toxicological analyses regarding alcohol in blood.*

Year	Negative (*n*)	Positive (*n*)	Not tested (*n*)	Total (*n*)	Tested (%)	Positive, tested (%)	Positive, total (%)
1975–1979	52	13	22	87	75	20	15
1980–1984	43	6	9	58	84	12	10
1985–1989	35	9	11	55	80	20	16
1990–1994	28	13	9	50	82	32	26
1995–2000	26	6	3	35	91	19	17
Total	184	47	54	285	81	20	16

TABLE 2—*Places of fatal injury events caused by electricity in Sweden, 1975–2000.*

Place of injury event	Occupational (*n*)	Leisure (*n*)	Unknown (*n*)	Total (*n*)	Total (%)
Railway	23	41	—	64	22
Residential properties indoors	2	49	2	53	19
Substation	25	5	—	30	11
Farm/cow house	19	6	—	25	9
Courtyard/garden	-	21	—	21	7
Industry/workshop	15	3	—	18	6
Construction site	15	1	—	16	6
Power line pole	12	3	—	15	5
Water area	1	10	—	11	4
Main road/street	8	2	—	10	4
Forest/field	4	5	—	9	3
Other	8	5	—	13	5
Total	132	151	2	285	100

TABLE 3—*Location and voltage of aerial power line contributing to death.*

	Occupational		Leisure		
Location	High voltage (*n*)	Low voltage (*n*)	High voltage (*n*)	Low voltage (*n*)	Total (*n*)
Railway	23	—	38	—	61
Forest/field	9	6	8	—	23
Public road	6	—	1	—	7
Substation	4	—	1	—	5
Farm/cowhouse	3	—	2	—	5
Water area	—	—	3	1	4
Construction site	2	1	—	—	3
Courtyard/garden	—	—	2	1	3
Industry/workshop	—	—	1	—	1
Residential properties	—	—	—	1	1
Total	47	7	56	3	113

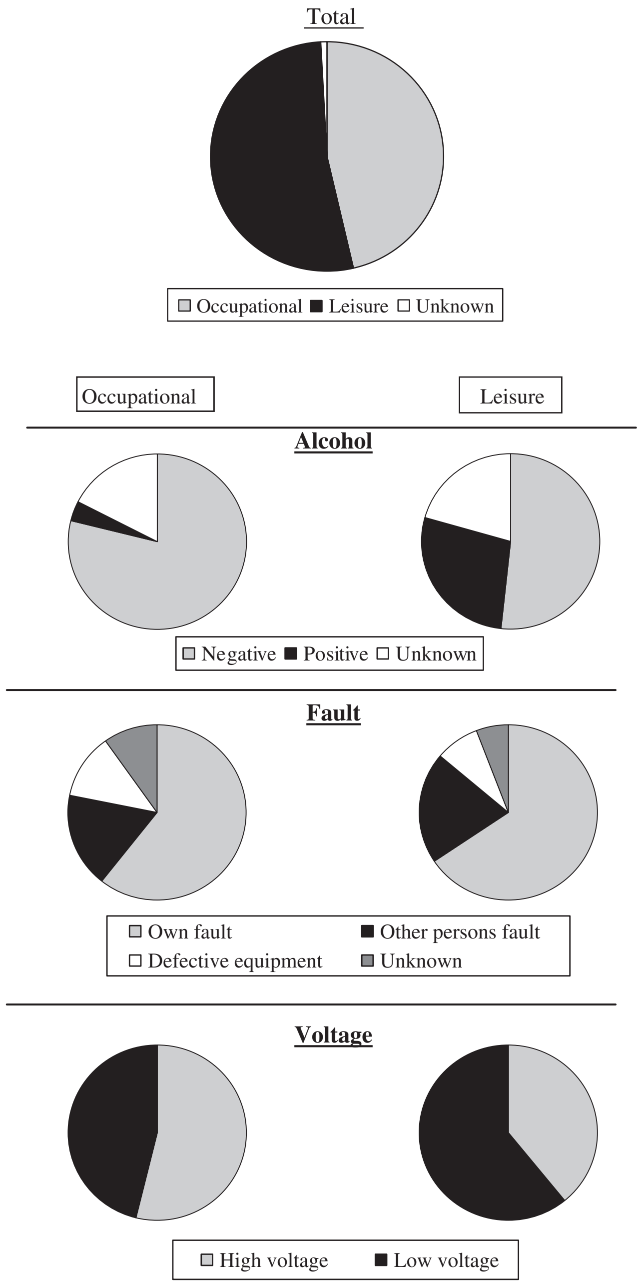

FIG. 4—*Comparison between occupational and leisure time deaths due to electricity regarding alcohol, fault, and voltage.*

Twenty-five (9%) of the deceased were treated as inpatients following the injury event for a total of 277 days; most of these were treated for burns.

Occupational Deaths

All 132 occupational victims were men with a median and mean age of 42 years (range 17–82) (Fig. 6).

Sixty-one (46%) of the workers were "electricians," including 31 electric linesmen, 19 electrical fitters and wire-men, six electrical/electronics engineers and technicians, and five operators of stationary engines and related equipment. Among the 71 "non-electricians," agricultural workers formed the largest sub-category (Table 6).

TABLE 4—*Activity at the time of the fatal injury event. Children and adolescents.*

Activity	Age 0–12 (*n*)	Age 13–19 (*n*)	Total (*n*)
Climbing			
Railway carriage	1	20	21
Power line pole	—	3	3
Substation	2	—	2
Other	2	—	2
Contact with			
Aerial power line through high object	—	3	3
Electric socket	3	—	3
Lamp socket	2	—	2
Electric stove	1	—	1
Electric heater	1	—	1
Extension cord	—	1	1
Other electric appliances	—	3	3
Maintenance/construction	—	2	2
Other activity	—	4	4
Total	12	36	48

Alcohol was analyzed in both blood and urine in 104 (78%) cases. Five (5%) tested positive for alcohol in blood and in an additional case a linesman had alcohol detectable (0.3 g/L) in urine only.

One-sixth ($n = 23$; 17%) of the fatalities took place on railway sites and 25 were electrocuted at substations. Construction sites were represented in 15 cases. Only one of these occurred during the last 10 years of the study. High-voltage events caused just over half ($n = 71$; 54%) of the deaths (Fig. 4).

Sixty-five percent (80/123) of the occupational victims were determined to have contributed to their own death, often neglecting proper use of protective devices and procedures (Fig. 4). This was especially common among "electricians," who were estimated to be at fault in 84% (47/56) of the cases.

Leisure Time Deaths

Mostly younger persons were found among the 151 leisure time deaths. The mean age was 35 years (range 10 months–92 years) and the median age was 28 (Fig. 6).

Forty-two were tested positive for alcohol in blood (42/120; 35%), and four cases tested positive for alcohol in urine only. Almost half of these ($n = 21/46$) were climbing railway carriages

TABLE 5—*Activity at the time of the fatal injury event in victims testing positive for alcohol.*

Activity	Deaths (*n*)	Total (*n*)
Climbing	—	24
Railway carriage	20	—
Power line pole	1	—
Substation	1	—
Other	2	—
Maintenance/construction	5	5
Falling onto electrified rail at subway	3	3
Conveyance of vehicle or ship	—	3
Truck	1	—
Boat	1	—
Tractor	1	—
Woodcutting	2	2
Doing laundry	2	2
Illicit alcohol production	2	2
Other activities	6	6
Total	47	47

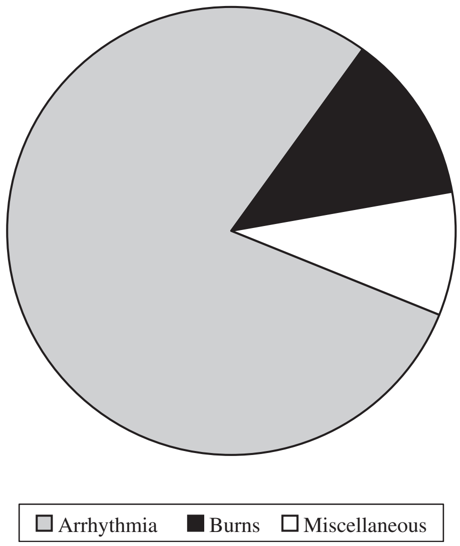

FIG. 5—*Causes of death in fatal accidental injury events due to electricity.*

at the time of the fatal event. More than half were 15–29 years of age. Of all tested leisure time victims, nineteen (16%) had a blood alcohol concentration of 1.5 g/L or more (Fig. 3).

The distribution between high- and low-voltage current was 39% ($n = 59$) and 61% ($n = 92$), respectively (Fig. 4). The most common place of the injury event was the home of the deceased ($n = 49$; 32%), followed by railway sites (Table 2). Most of the railway victims ($n = 34$) had climbed onto the carriage and accidentally touched the overhead wire.

The deceased was evaluated to have caused the event in a majority ($n = 99/144$; 69%) of the cases (Fig. 4). Unauthorized repairs, use of alcohol, overlooking aerial power lines, or just lack of judgment were common examples of factors contributing to death.

Discussion

In Sweden, the use of electricity has increased steadily during the last century, while the incidence of electricity-related fatalities has decreased. Preventive measures during the study period, such as setting minimum standards, installing earth wires, improved wall sockets, and increased use of ground fault interrupters and arc protection devices have most likely contributed to this development. Other important measures are (i) a forced ban of sales for couplers for industrial purposes with metallic enclosures, (ii) introduction of an improved rubber compound for flexible cables, (iii) an improved directional earth-fault relay protection with automatic disconnection of the current when a live conductor of an overhead wire falls to the ground, (iv) guidelines to electricians of always verifying that the installation is "dead" before work is commenced, and that (v) it is more common today to make the collector wires of the railway tracks "dead" where railway carriages are parked (Håkan Lidman, The Swedish National Electrical Safety Board, personal contact).

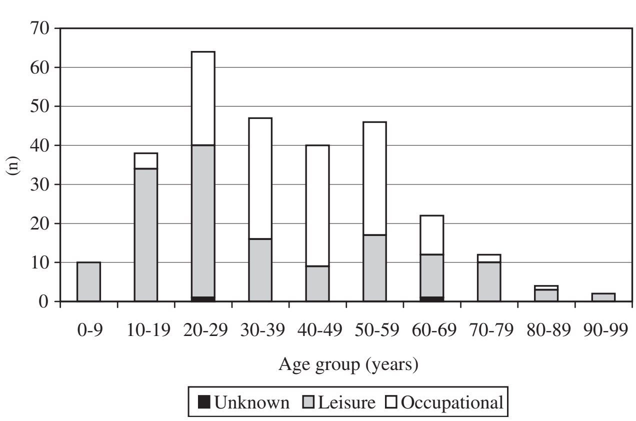

FIG. 6—*Activity in fatal accidental injury events due to electricity, by age.*

TABLE 6—*Occupational categories exposed to electricity-related fatalities in Sweden, 1975–2000.*

Occupation	Deaths (*n*)	(%)
Electrician	61	46
Agricultural worker	19	14
Construction worker	15	11
Industrial worker	10	8
Vehicle driver	9	7
Engineer	3	2
Military conscript	3	2
Other	11	8
Unknown	1	2
Total	132	100

This study illustrates the national incidence of electrocution during a quarter of a century. To our knowledge, there are no similar previous reports of this size that cover both occupational and leisure time fatalities and the involvement of alcohol.

Validity

When working with a material covering this length, different sources of error must be considered. One such source is missing cases due to erroneous classification and registration of data. This became evident when comparing the National Cause-of-Death Register with data from the Swedish National Electrical Safety Board. In both databases, there were cases not found in the other. The cases missing in the Cause-of-Death Register were mostly deaths due to cardiac arrhythmia following electric shock. These had most likely been overlooked in the manual registration. Others were incorrectly classified as burns or injuries from falls. By obtaining these additional cases, we were able to reduce the dropout number by thirteen deaths, making this study more complete than the official statistics.

Another problem related to the length of the study period was the difficulty in obtaining and evaluating incidence figures of different occupational categories. Changes in the social security registration concerning occupational injuries and the lack of censuses covering the last 10 years of the study were two important reasons for this. However, as the main goal was identifying the most common situations leading to electrocution, these possible flaws do not affect the general results.

As this is a retrospective study, it may suffer from some limitations concerning the analyses of circumstances surrounding the deaths. We believe firmly, however, that the results presented give a reasonable estimate of the impact of defective equipment in relation to human error, as professionals evaluated most of the cases.

Demographics

Traditionally, electrical work has been considered as a "male area," both at the workplace and at home. This stereotype seems to be confirmed when comparing incidences with respect to sex. In this study, there were no occupational fatalities among women and only a few during leisure time. This is similar to results from Australia (5,10) and the United States, where only occasional female fatalities have been described (3,6). Most likely, this imbalance is related to gender-related exposure to electricity.

"Electrician" was by far the most represented occupational category, followed by farmer and construction worker. This could be ascribed to the large amount of electrical tools being used, and the wear and tear of equipment in these professions. The fact that only one fatal incident occurred at a construction site during the last 10 years of the study may be explained by decreased exposure due to a recession in the construction industry, improved security, or both.

The mean age of occupational decedents in our study was 8–10 years higher than found in studies from United States and Australia (3–6). The difference is difficult to explain but could be related to a higher mean age of Swedish "electricians."

Incidence

During the entire study period, there was a decreasing trend both in occupational and leisure time fatalities. The trend was stronger in the occupational sector, possibly showing that improvements regarding regulations and equipment have been more far reaching at work places. In addition, the higher incidence of alcohol involvement during leisure time could explain some of the differences.

Comparisons with other countries are hampered as there are few similar studies and because denominator data are lacking.

Alcohol

Use of alcohol contributed significantly through acute inebriation, but possibly also through hangover effects in a few cases. The latter category included cases that tested positive for alcohol in urine but not in blood. Whether *all* of the victims were commencing the fatal activity as a direct effect of alcohol intake is impossible to say, as human error can also occur in sober individuals, but we believe that a large part of the alcohol-related deaths could have been avoided.

One-fifth of all tested victims tested positive for alcohol, but as 54 were not tested and 25 were treated at hospital 1 day or more after the incident, the real figure may be lower or higher (range 17–36%). In none of the hospital cases were there records of alcohol tests at admittance. Worth noting is that the percentage of test-positive victims has remained substantially unchanged during the period, which indicates that the reduction of deaths has been related to factors mainly unrelated to alcohol.

Only a few cases involved alcohol at work. These figures are lower than those in a Swedish study from 1996 (unpublished data) where alcohol-related occupational deaths during 1 year constituted 8%.

Prevention

We conclude that the strategies to reduce electricity-related fatalities have proven effective. As expected most leisure time deaths were due to low voltage, in accordance with the most likely exposure. More unexpected was the finding that high-voltage events constituted 39% of the leisure time deaths. These were mainly due to contact with aerial power lines at railway sites. Even though this kind of event became more uncommon toward the end of the study period, further measures could be taken to avoid future deaths. Shielding off dangerous sites is an often-used method at substations. Railway sites, however, have other demands of accessibility. Alternate ways of approaching the problem could include altered construction of carriages, making them less climbable, or making the current supply less exposed. Information is another approach, but technical solutions and legislation most probably have a larger influence, as changes in behavior are difficult to achieve through information only (20,21). This aspect is even more important when discussing the impact of alcohol.

In the low-voltage area, the main goal should be to reduce the hidden dangers of wornout electric appliances, e.g., extension cords. Again, improved legislation and increased awareness through information are important preventive strategies. Another method, often referred to in electricity safety discussions (3,5,10,22), is the use of ground fault interrupters. These are devices comparing the supply and return of current in an electrical circuit, disconnecting the supply if there is an imbalance. The reaction time is usually around 0.03 sec and the sensitivity is 0.03 A (23). This prevents anyone, intoxicated or not, from being electrocuted by objects conductive through defects in isolation. The ground fault interrupter also prevents electricity-induced fires (23). Guidelines of installing ground fault interrupters at the switchboard of construction sites and in new houses have been practiced in Sweden since the mid-1990s and became mandatory in the year 2000 (24). Although the ground fault interrupter does not protect against all kinds of faults, such as conduction between phase and neutral, it will probably contribute to a further reduction of the death rate.

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