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Fatal electrical accidents in Finland 1980–2019 – trends and reducing measures

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Abstract

This paper analyses the content of fatal electrical accident records (n=157) in Finland during the years 1980–2019 in order to identify and classify accident types and causes. During the 40-year period, the death rate from electrical accidents has decreased from 0.29 per 100,000 people per year to 0.00-0.07 in the last decade. The number of accidents rooting from accidentally touching live parts and by making illegal electrical installations has plummeted. Of all fatalities, 37% could probably have been prevented if the circuit had been protected with a residual current device, which is now mandatory in new installations. The most common electrical accident in 2010–2019 was an electric shock from a railway overhead power line. Of fatal electrical accidents, 76% occur between April and September and 92.5% of victims are male. Child casualties are very rare. The level of electrical safety can be considered acceptable, but educating the public still has room for improvement.

1. INTRODUCTION

As electricity with potentially dangerous voltage levels is used all over the world in everyday life, electrical safety is a concern both for occupational and free-time safety. In Finland, the first documented fatal electrical accident happened in Jumalniemi sawmill in 1897 when worker Jeremias Leskinen touched uninsulated electrical wires (Hieta-Wilkman & Dammert, 2015). According to a newspaper report, the wires were in a wooden casing and the victim and his co-worker were first ordered to install a lid to cover the wires. When the workers were away, the electric machine was started, and when Leskinen returned, he probably mistakenly thought that the voltage was not present, touched the wires and received an electric shock. ("Sähkö Tappanut," 1897) Five years later, the first law concerning electrical safety was issued in the country. Although electrical safety legislation in Finland and all over the world has since improved and voltage testers and protective gear are inexpensive, this kind of accident is similar to modern fatal electrical accidents: a person touches a part that is supposed to be disconnected from dangerous voltage.

Electrical accidents can be classified into two main categories: arc flash accidents and electric shock accidents. In an arc flash accident, a sudden high current flowing through air, usually resulting from a short circuit, results in a discharge dissipating heat and visible light. In addition to thermal impact, the shock wave and molten metal particles, poisonous gasses and acoustic bang may cause injuries. (EN 50110-1, 2013) In an electric shock, an electric current flows though human body and can cause loss of muscular control or death. The exact consequences of electric current vary individually and depend mainly on the duration of the shock and the magnitude of the current (IEC 60479-1, 2018), and it is unfeasible to set a hard limit to a dangerous current level. However, generally a continuous current of 50–150 milliamperes can cause death (OHSA, 2002).

In the United States, 2,287 workers died from shock or electrical burn injuries between 1992 and 1998, while electricity ranked sixth of all causes of occupational fatalities in the country (Cawley & Homce, 2003). The compilation of statistics on electrical accidents varies by country. Table 1 presents some values from international literature.

Table 1. Electrical accident fatality rates from literature

Area	**Fatality rate (per 100,000 per year)**	**Category**	**Time span**	**Source**
United States	0.1–0.2	Occupational	2003-2018	(ESFI, 2020)
United States	0.3 (including lightning strikes)	Full population	2019	Computed from Zemaitis et. al. (2020)
Northern Ireland	0.14	Full population	1982-2003	(Lucas, 2009)
Bulgaria	1.29	Full population	1980-2006	(Dokov, 2008)
Western Australia	0.52	Full population	1977-1990	Computed from Fatovich (1992)

This paper aims to analyse Finnish electrical accidents in order to reveal trends in accident types and find recommendations to further increase electrical safety. The paper covers only fatal electrical accidents, not including suicides, deaths caused by lightning strikes and deaths resulting from a fire caused by electricity, as they are not classified as electrical accidents in Finland. Deaths by lightning strikes are very rare in Finland, there are only 10 casualties recorded in the Finnish Official Cause-of-Death Statistics OCDS in years 1998–2018.

2. MATERIALS AND METHODS

In this paper, the fatal electrical accident data from Finnish national electrical safety authority (Tukes) is analysed. As provided by the electrical safety legislation, police, rescue and work safety authorities and distribution network operators are obliged to report severe dangerous situations and severe accidents to Tukes. The Tukes accident database includes a short summary of accidents and their causes, such as the following:

> *March 2003: Electricians were constructing a new 20 kilovolt local distribution power line, which crosses an old uninsulated low voltage powerline. The electrician who climbed to the electric pole went into contact with the live conductors of the old line. The man got an electric shock and fell into ground. The man was found dead.*

The accident data have slight discrepancies when compared to OCDS from Statistics Finland. In the 39-year period 1980–2018, there are 157 electrical deaths in Tukes database and 173 electrical deaths in OCDS, the difference averaging 0.41 deaths per year. As the OCDS data is practically 100% complete (Kannus et al., 2019), the underreporting of electrical accidents to Tukes is the probable cause for discrepancy. One plausible explanation is that not in all rural police departments does the investigating officer know that electrical deaths should be reported to Tukes. Both databases exclude deaths from lightning strikes and suicides. According to Statistics Finland (Pajunen, email, October 8, 2020) and Tukes (Tulonen, email, October 7, 2020), there are no changes in assigning the electrical accident statistics during the period 1980–2018, that could bias the observations. The accident data is analysed both narratively to identify common factors leading to accidents and quantitatively to discover trends in accidents. As the accident records are comprehensive for the full population and not a specific cohort or sample, no separate statistical analysis for reliability is needed.

3. RESULTS

The number of fatal electrical accidents has been declining during the entire period. In 1980, 14 people died from electrical accidents. In 2010–2019, only 0–3 people each year died from electrical accidents. Meanwhile, the population of Finland has increased from 4.8 million (1980) to 5.5 million (2019). Figure 1 presents the death rate per 100,000 people per year, compared to death rate due to all accidents. In other than electrical fatal accidents, the death rate has not decreased substantially when compared to the continuously decreasing trend of electrical deaths.

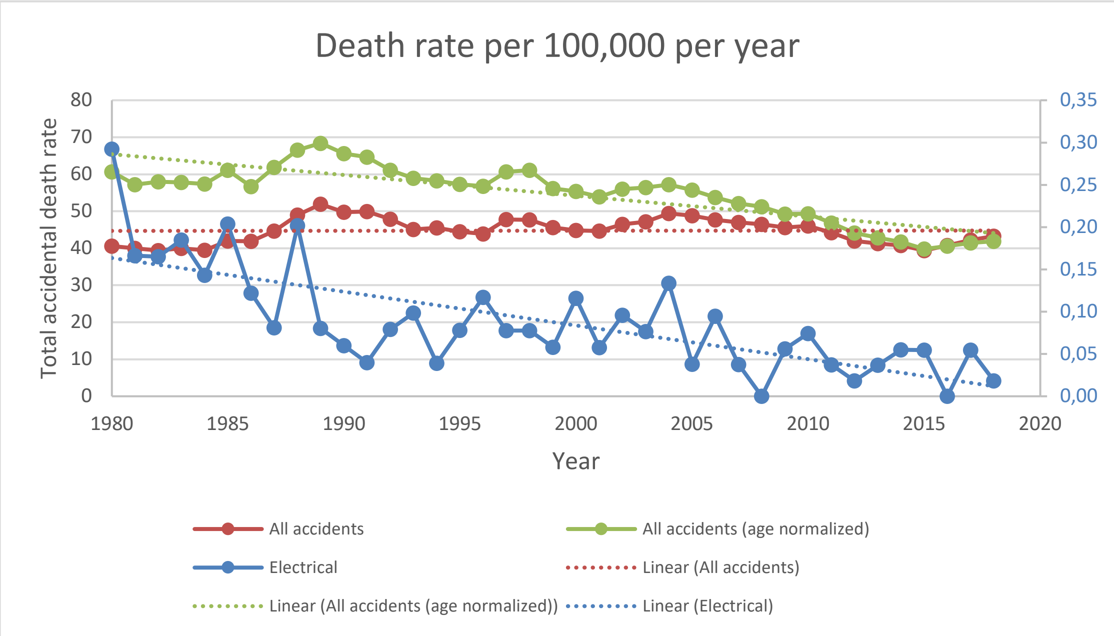

Figure 1. Electrical accident death rate per 100,000 inhabitants per year, compared to death rate due to all accidents

Content analysis was performed for the accident records (n=157) and six main categories for the accidents were identified, as illustrated in Table 2. The total number of fatal accidents is presented for comparison.

Table 2. Finnish electrical accidents analysed and classified into six categories.

Category	Years 1980–1989	1990–1999	2000–2009	2010–2019	Total
Contact with railway overhead lines	2	5	3	7	17
Contact with other uninsulated overhead power lines	16	8	12	3	42
Contact with other live parts (accidentally or by assuming the part is isolated from power)	22	2	3	1	39
Illegal do-it-yourself - installations or devices	24	6	7	5	28
Faulty or damaged appliance	3	6	4	2	15
Miscellaneous or reason unclear	5	5	4	2	16
Total electrical deaths	72	32	33	20	157
Total accidental deaths	20959	23792	24556	23142	92449

3.1. Contact with railway overhead lines

In Finland, all main railways are electrified. The power is delivered by 25-kilovolt overhead power wires, and the rails and the body of the rolling stock act as ground. Therefore, standing on the roof of the car and touching or going too close to (≈ 1cm) the overhead line will cause an electrical accident. This kind of accident was the most common cause for electrical deaths in the last decade (n=7). The victims are typically young or adolescent males. The following record presents an example from November 2011:

> *A young man climbed onto the roof of a train, got an electric shock from the overhead line and fell to the ground. He died from the accident.*

The reason for the prevalence of this kind of accident is that all other accidents have been successfully mitigated but it is still possible to climb on a train and receive an electric shock.

3.2. Contact with other uninsulated overhead power lines

Until the 1960s, power distribution to houses was usually implemented with uninsulated overhead low voltage (400 V) wires. These kinds of lines have been replaced with insulated bundle power cables (AMKA cables), but uninsulated overhead low voltage wires can be still seen in rural areas in Finland. As Finland is not in an earthquake-affected area, ground cables are used in densely populated areas.

For high voltage power transmission, uninsulated power lines (voltages typically 20 kV, 110 kV and 400 kV) are still prevalent. For medium range distribution (10–30 km), 20 kV lines are currently being replaced with ground cabling to ensure weather-proof power transmission and distribution. As Finland is covered with forests, trees falling on 20 kV overhead lines are the most common reason for blackouts in rural areas and expensive and slow to repair after a storm or a treefall caused by extensive snow load.

A typical accident with overhead power lines is one in which a truck driver hits an uninsulated 20 kV power line with a vehicle-mounted crane when unloading. In the last decade, there were three overhead power line related accidents, of which two were unloading trucks. The following excerpt presents an example from August 2017:

> *An element assembler was unloading a concrete element load with a truck-mounted crane when he got an electric shock from a nearby overhead power line.*

The third overhead power line accident happened to a professional electrician when he was building a new power line. As the killed electrician was from a foreign contractor, an extensive English investigation report is available (Hatakka et al., 2013). The electrician working on the new line did not tighten the mounting bolt of the temporary earthing tool adequately. The earthing tool fell off and the electrician was electrocuted by voltage induced from an adjacent intact power line.

3.3. Contact with other live parts

This accident category consists of accidents in which the victim accidentally touches or goes too close to live conducting parts or incorrectly assumes that the part is isolated from power and touches it deliberately. These kinds of accidents were common in the 1980s (n=22), but they have drastically decreased in 1990–2019 (n=6). For instance, the only accident of this type in the 2010s was at a demolition site in October 2013:

> *A man was killed at a demolition site due to going too close to a transformer.*

According to a newspaper report ("A man was electrocuted in Espoo Centre," 2013), two men illegally intruded a demolition site at night and one of them went too close to a transformer and was killed.

The previous accident of this type happened to a team of electricians working at a 20-kV transformer in July 2009. The group incorrectly assumed that the disconnecting switch was open, but one of the three phase connectors was stuck (Hatakka & Johansson, 2009). The group neglected to verify by measuring that the transformer was dead and neglected the temporary earthing. One of the electricians received a lethal shock from the transformer.

In the 1980s, these kinds of accidents were more common and also occurred in workplaces and households. The following examples are from December 1980, September 1984 and July 1989 respectively:

> *A child was electrocuted when putting a key to a wall socket next to a draining board, while simultaneously leaning on the draining board.*

> *A child pushed two nails to a 0-class [=unearthed] wall socket and got a lethal electric shock. The wall outlets were not security outlets.*

> *Replacing an overhead line in a farm courtyard was interrupted when the replacing insulated overhead cable was found to be too short. A week later, the electrician continued the work and lowered the cable from the pole and removed the shields from the phase conductors, without making the cable dead. When attempting to pull the cable straight, he got touched by two live phase conductors and got a fatal electric shock.*

3.4 Illegal do-it-yourself installations or devices

These kinds of accidents have decreased since the 1980s, but they still occur. A typical example is one in which a wall outlet is miswired so that the protective ground contact is connected to the live wire, not the neutral wire. After this miswiring, all devices based on protective earthing of the case have lethal 230 V voltage on them (instead of being grounded). In January 2015, the following accident occurred:

> *A plumber got a lethal electric shock via a tool connected to the outlet in the bathroom. The outlet was misearthed by connecting the protective earth connector to the live wire instead of the neutral one, and therefore, the earthing contacts were live.*

Similar miswirings have killed a young man touching the pole of a caravan connected to a misearthed outlet (August 2003), another young man operating a rented aerial access platform at home (July 2001) and a 73-year-old man using a water pump at his summer cottage (May 1995). One variant of this accident results from a self-made extension cord missing the protective earth wire or taking the power inside a building from an unearthed outlet and using a safety-earthed device outside via that cord. While this does not cause an immediate accident, the missing grounding will not cause the fuse or circuit breaker trip if the appliance has an internal fault, which causes a dangerous voltage to leak to the body of the appliance. For instance, a man using a pressure cleaner powered via an illegal self-made unearthed extension cord was killed in August 2004 and another in May 1992 while using portable water pumps outside by taking the power inside from an unearthed outlet.

One sub-category of these kinds of accidents are self-made electrical installations showing very gross negligence. Whereas a layman does not necessarily know that using an extension cord to take power from inside an unearthed outlet to a courtyard and assembling an extension cord without protect earth wire can be interpreted as normal negligence, it is evident for anyone that the following accidents are a consequence of shoddy, dangerous pieces of work:

> *A barefooted schoolchild was picking berries next to a fence built around a garden when they got a lethal electric shock from the fence. The fence was a self-made electric fence with 220 V mains voltage connected to its iron wires. (July 1980)*

> *A man was electrocuted by tripping over a self-made device for finding angleworms. The victim had connected one wire of a two-wire cable to a metal body of a lamp and connected the cable via an extension cord to an interior wall outlet. (July 1988)*

A male pensioner had assembled a rodent repelling device from a wall plug, cable and two screwdrivers. The other screwdriver was connected to live wire and the other to the neutral wire. For an unknown reason he had gripped the screwdrivers or live wires, when the plug was connected to wall outlet. The man got an electric shock and died later in a hospital. (August 2002)

International literature reveals similar accidents with angleworm searching (Bux et al., 2003).

3.5 Faulty or damaged appliances

Faulty or damaged appliances are a rare reason for electrical fatalities in Finland. A broken light switch (June 2000), a gouged welding machine (August 2000), a drill with a broken power cable (June 2004), a compressor with insulation fault (August 2006) and broken portable lamps in May 2018 and June 2019 resulted in a total of six deaths in 2000–2019.

3.6 Miscellaneous or reason unclear

This category contains the fatal accidents that do not directly fit into the other categories or in which the accident record is too obscure to judge the key reason for the accident. For instance, a record from June 1999 describes the following accident:

The victim was found dead next to a water pump. Depending on the position of the wall plug, the frame of the pump might have been live.

The reason was classified as unclear because it cannot be determined whether the reason was an improperly self-installed plug, self-made repair or a defect in the pump.

3.7 An RCD as an efficient remedy

All the accident cases were assessed to determine whether the installation was protected with a residual current device (RCD). Residual current devices monitor the current difference between the live and the neutral wire and cuts the power if the current difference exceeds 30 mA. In new installations, RCDs have been mandatory in bathrooms and exterior wall outlets since 1997, in all wall outlets (with the exception of fridges and similar, usually non-moveable, safety grounded appliances) since 2007 (Tiainen & Härkönen, 2019) and in domestic lighting circuits since 2017 (SFS 6000, 2017). As the typical lifespan of electric installations is 50–60 years and legislation is not retroactive, it will take time for RCDs to appear in accident statistics.

As revealed by analysing the accident records in 1980–2019, 37% of fatalities might have been avoided if the installations were protected with a residual current device (RCD). For instance, the following accident occurred in July 1996:

A child tried to reach a toy near a floor lamp and simultaneously touched the lamp and a radiator. The body of the lamp had live voltage in it, and the child got a lethal electric shock. The reason for the accident was defective insulation between live wire and tubular metal branch on the top of the lamp.

In this kind of situation, the current flowing through the body of the child results in a drop of the current in the neutral wire of the socket outlet, and the RCD cuts the power. Figure 2 illustrates the yearly accidents and those that could be prevented with an RCD.

The absolute impact of RCDs is difficult to assess reliably, as there exists no record for lives saved by a tripping RCD. The reduction in household accidents can also be accounted for by improved security thinking and safety wall sockets.

3.8 Age and gender

Electrical deaths are strongly gendered: only 7.5% of all electrical death victims are female. There have been no female victims of electrical accidents since 2002 in OCDS or Tukes database. Child victims are also very rare: according to OCDS, in the age group 10–14, only three children died from electrical accident in 1998–2018. According to Tukes records, all three accidents involved climbing on the top of an electric train at railway yard and getting a shock from the 25-kV overhead line. In the same time period, only one child under 10 years died from an electric shock. No Tukes record of the incident exists. The most recent Tukes record mentioning a small child getting killed is the previously mentioned example of the child receiving an electric shock from the floor lamp in 1996.

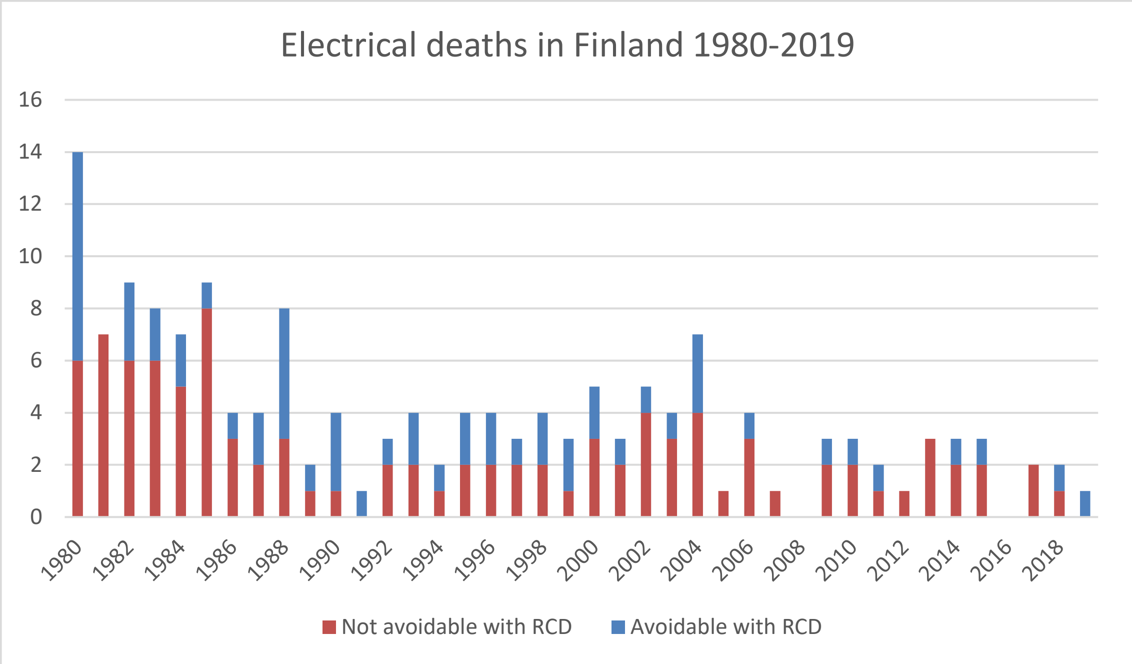

Figure 2. Total electrical deaths in Finland 1980–2019

3.9 Seasonal distribution of electrical fatalities

Of fatal electrical accidents, 76% happen between April and September, peaking in July (Figure 3).

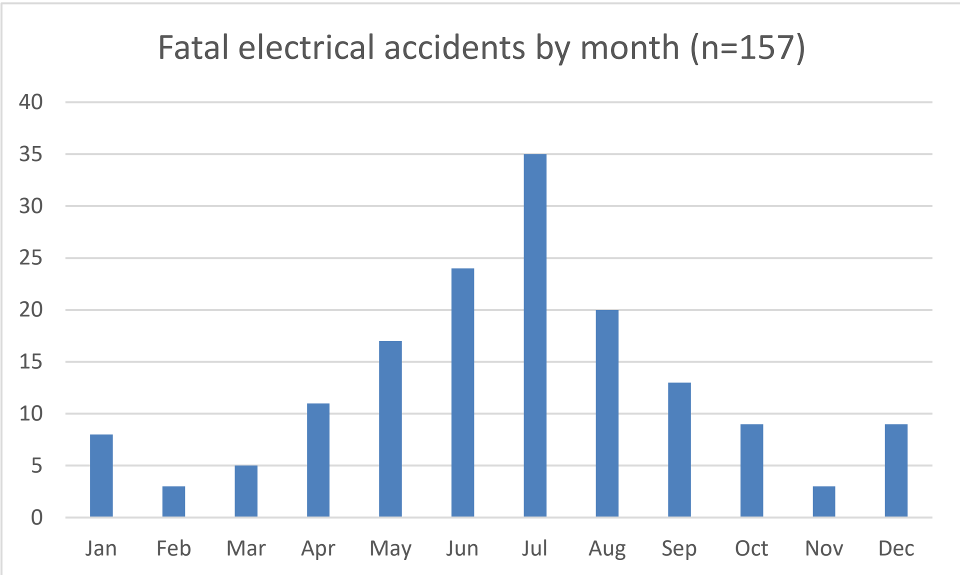

Figure 3. Monthly distribution of fatal electrical accidents

This is consistent with data from other studies: electrical accidents do peak in summer (Fatovich, 1992; Dokov, 2008; Dokov, 2010).

3.10 Miscellaneous observations

It is noteworthy that all recorded electrical deaths are single-victim ones, except for one incident in May 1985 in which a 20 kV arc flash accident killed two electricians in a paper mill.

Of all 157 incidents, 14 happened on a farm. Half of them were caused by illegal self-made installations or assemblies. Strong do-it-yourself-culture is a plausible reason for the overrepresentation of farms. In 2011, the union of farmers, an insurance company and a counselling organisation launched an information campaign in order to improve electrical safety on farms ("Flaws in electrical safety in farms", 2011). The latest farm-related lethal electrical incident was recorded in 2004.

No electronics hobbyists nor radio amateurs are mentioned in accident data, except for one schoolchild, who died when troubleshooting a mains powered light organ that they built from a construction kit in January 1984.

In 98 cases (62%), the acts of the victims themselves can be argued to be the root cause for the accident. In 36 cases (23%), the responsibility is left unclear or the work was done in a group. In 23 cases (15%), no neglect can be determined in the victims' actions.

Only one fatal accident (January 1983) has happened in an educational institute, while doing a low voltage laboratory measurement.

A majority of the victims (n=92 or 58%) were ordinary people (non-electricians) who were electrocuted in their free time. The rest are occupational accidents, 42 victims (27%) being ordinary people or trainees and only 24 victims (15%) professional electricians.

In the seven accidents of professional electricians after 2000, four happened because the electrician or team of electricians neglected the mandatory part of measuring that the isolated part of the circuit is really dead before starting the work.

4. DISCUSSION

In comparison to other unintentional injury deaths in Finland, fatal electrical accidents are very rare. Falls, road traffic crashes, alcohol poisonings and other poisonings are the leading causes for unintentional injuries among Finnish people (Kannus et al., 2019). For instance, in 2016, the death rate (per 100,000 persons) was 23 for women and 29 for men in falls and 2 and 7 in road traffic crashes, respectively. Compared to this, the yearly death rate of under 0.05 deaths per 100,000 persons is negligible.

The fall of electrical death rate from 0.3 to 0.05 cannot be explained by a single reason. The following factors might have a plausible role in the mitigation of accidents:

- Overall improvement in general safety culture. The public better recognises the dangers of electricity, and electrical installations are outsourced to professional electrical contractors.
- Overall improvement in professional safety culture. According to Dr. Tuuli Tulonen (2020), Senior Officer specialised in electrical accidents in Tukes, the level of both the education and the safety attitudes of electricians has improved from the 1980s. Using one's fingertip as a voltage detector or getting electric shocks are no longer considered to be "part of the job".
- Regular electrical work safety training for professionals. Since 1999, there has been mandatory regular (every five years) electrical work safety training for electricians. The training is usually a one-day course, consisting of reviewing severe accidents in previous years and changes in regulations. Among Finnish professional electricians, being in a hurry is experienced as the biggest electrical safety risk (Tulonen, 2010). This can be reduced by organisational measures.
- Active education for the public. Electrical safety authority (Tukes) reports fatal electrical accidents to media and runs educative campaigns, such as a television advertisement campaign in the late 1990s, which satirised an illegal "electrical contractor" (Korkeamäki,

1997), and in the 2010s, the “Involving danger to life” campaign on social media (Tukes, 2012) to warn about the dangers of overhead power lines.

- Safety outlets that have insulating barriers that let the plug in only if pressure is applied to both contact holes in the sockets prevent accidents in which a small child tries to put a key or a nail to a wall socket.
- As discussed before, use of residual current devices became mandatory in some destinations in 1997 and since 2017, they are mandatory in almost all household electrical installations.
- Since 1997, 0-class wall sockets have been banned in new installations. Therefore, no 0-class electrical appliances (appliances with only basic insulation) have been on the market, and they have been replaced by II-class devices with either double-insulation or reinforced insulation.
- Since 1989, a separate protective earth conductor identified with a yellow-green colour has been mandatory in new wiring. This may have an impact on the safety of illegal do-it-yourself installations, as mixing the line and neutral wires will not cause the frame of a device to become live. When a layperson decides to illegally replace a damaged wall socket by themself, it is easy to see where the wires are to be connected, compared to the old system in which only live and neutral wires entered the outlet and the protective earth connector was to be connected to the neutral wire with a jumper wire.
- In the past two decades, cordless tools, such as battery-powered drills and lamps, have replaced traditional ones. This both reduces the need for extension cords and naturally protects the user from receiving an electric shock from the tool itself.
- When joining the European Economic Area (EAA) in January 1994, pre-market inspection of electrical appliances was abandoned in Finland and replaced with market supervision. Free markets have reduced prices of electrical appliances and extension cords, which might have reduced illegal and dangerous do-it-yourself repairs. Also, general attitude to do-it-yourself repairs has changed and it is easier and usually even cheaper to buy a brand-new extension cord than to try to fix a damaged one with insulating tape.
- Pole transformers have been extensively replaced with booth-type transformers in the 2000s, which hinders accidents from climbing near live parts. This development together with replacing 20 kV overhead power lines with ground cables has and will reduce accidents in future.

5. CONCLUSIONS AND FURTHER RESEARCH

Measured by electrical fatalities, electrical safety has been internationally compared on an acceptable level and still improved during the time period of 1980-2019.

The following recommendations can be motivated by the results:

- Railway overhead line accidents of adolescent male victims: education in schools and on social media. Hindering the climbing on railway cars and making the warning signs more specific and informative.
- In Finland, RCDs have been mandatory for all new wall sockets and lighting circuits, with rare specific exceptions, since 2017. Globally pushing electrical safety legislation to make RCDs mandatory in domestic installations can cut electrical fatalities.

Compilation and publishing of statistics on electrical accidents vary by country, especially for free-time electrical accidents, and the information is usually easily available only in the national language. As Batra and Ioannides (2001) conclude, reliable internationally comparable data on fatal electrical accidents apparently do exist but there are differences in obligatory notification practices and in how data are recorded. Further research is needed for comparing electrical death reasons between different countries and protective measures in national legislation in order to discover good practices for reducing electrical deaths. There are national differences in accident types: for instance, electrical shock drowning incidents in natural water are completely inexistent in Finland but have killed multiple persons in the United States (Morse et. al., 2020; Linja-aho, 2020).

This study analysed only fatal electrical accidents. Studies on records on non-fatal accidents from insurance companies and public health service could provide more information on common electrical accidents and near-miss incidents and help to clarify safety education and legislation.

Although electrical accidents cause typically 0-3 deaths per year in Finland, electrical fires kill 15 people per year on average (Tukes, 2019). According to studies in Finland, the most common reason for a fatal or non-fatal electrical fire is misuse of a stove or an oven (Nenonen, 2007; Nurmi et. al., 2005).

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