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Low-voltage electrical accidents, immediate reactions and acute health care associated with self-reported general health 4 years later

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ABSTRACT

Background and aims: Electricians frequently experience low-voltage electrical accidents. Some such accidents involve long-term negative health consequences. Early identification of victims at risk for long-term injury may improve acute medical treatment and long-term follow-up. This study aimed to determine acute exposure, health effects and treatment associated with general health ≥ 2 years after low-voltage electrical accidents.

Methods: In a cross-sectional study, 89 male electricians who had experienced an electrical accident between 1994 and 2001 participated in a 2003 follow-up health examination. They were identified from a registry of low-voltage electrical accidents and included in the study. Based on exposure descriptions in the original accident reports, they were stratified into the following three groups: a current arc accident group (N = 34, mean age 38.8 years [standard deviation, SD = 12.2, range = 21–59]) and two groups with the passage of current through the body, either fixed to the current source ("no-let-go" group; N = 35, mean age 34.0 years [SD = 10.5, range = 21–57]) or not ("let-go" group; N = 20, mean age = 38.7 years [SD = 10.3, range = 21–63]). They retrospectively described acute reactions and assessed their current general health at the health examination. Multivariate linear regression, ordinal logistic regression and Fisher's exact test were used to compare acute reactions with health at follow-up in each exposure group.

Results: The multivariate analysis indicated that after accidents with the passage of current through the body, severe acute headache (β = – 0.56, p = 0.013), years since the accident (β = – 0.16, p = 0.017) and the accident being perceived as frightening (β = – 0.48, p = 0.040) were negatively associated with general health ≥ 2 years later (R^2 = 0.25,

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$p = 0.002$). If the exposure included a no-let-go experience, then acute severe body numbness ($\beta = -0.53$, $p = 0.029$) was also negatively associated with general health ($R^2 = 0.38$, $p = 0.002$). Without such experience, only acute confusion ($\beta = -0.90$, $p = 0.029$) was negatively associated with the health at follow-up ($R^2 = 0.24$, $p = 0.029$). In univariate analyses, after the *passage of current through the body,* acute dizziness ($p = 0.029$), apathy ($p = 0.028$), confusion ($p = 0.007$) and irregular heartbeat ($p \leq 0.05$) were associated with poor long-term general health. The no-let-go group, more often than the let-go group, reported panic ($p = 0.001$), fear of death ($p = 0.029$), confusion ($p = 0.014$), exhaustion ($p = 0.009$), bodily numbness ($p = 0.013$) and immediate unconsciousness ($p = 0.019$). Acute symptoms beyond the first day after a current arc accident were associated with poor long-term general health ($p = 0.015$).

Discussion and conclusions: The acute reactions negatively associated with general health ≥ 2 years after low-voltage electrical accidents should alert the clinician in the acute phase after an electrical accident to the risk of developing negative long-term health effects. Future studies should specify long-term health beyond the concept of general health.

1. Introduction

Electricians are frequently exposed to low-voltage electrical accidents. However, such accidents can happen to anybody. In the Norwegian power production and distribution industry, which has approximately 40,000 employees, the estimated annual incidence of such accidents perceived as severe by the victims is approximately 3000 [1]. Low-voltage electrical accidents include shock with the passage of electric current through the body and current arc injuries without the passage of current through the body. Most low-voltage accidents have no or few acute/long-term consequences, while some of them are followed by severe long-term health problems [2,3].

The predictors of long-term effects of low-voltage accidents are not well documented. Thus, we aimed to identify the acute predictors of long-term general health effects following low-voltage accidents.

Health effects of electrical injuries (EIs) [4,5] may involve neurological injuries, cardiovascular reactions, musculoskeletal complaints, burns or skin injuries, and cognitive or psychological disorders [6–9]. Nevertheless, when the aim is to identify the acute predictors of long-term health after an accident, a concept of general health without further specification [10] may sufficiently well reflect the health effects of EIs, because such a subjective health indicator is multidimensional and includes both physical and mental health [11].

Health effects may appear immediately, and be transient, prolonged, or permanent [12]. In a longitudinal study, patients with EIs reported persistent somatic, cognitive, and emotional complaints that were not directly related to the voltage exposure level, for an average duration of 3.9 years after injury [13].

Symptoms have also been described as diffuse and slowly developing, or delayed, sometimes considerably, and progressive, with an onset ≥ 1–5 years after an EI [12,14,15], often without any initial pathological findings [14].

While Grube et al. [16] reported that low-voltage injuries were unlikely to have permanent sequelae, Theman et al. [17] later found that most patients with low-voltage EIs had neurological (92.5%), psychological (90%) and musculoskeletal (72.5%) symptoms. These findings of Theman et al. are supported by other studies that also highlighted long-term sequelae of low-voltage EIs [18–21].

For early initiation of effective treatment after EIs, the identification and recognition of the possible predictors of short- and long-term outcomes after EIs have been suggested [22]. Predictors may be identified among the various *exposure characteristics* of an electrical accident and may vary depending on the outcome. Whether the exposure is extreme heat or noise from an electric arc or the passage of electric current through the body is a crucial factor [17,23,24]. In the case of the passage of current through the body, voltage is often registered as a voltage score or as low- (<1000 V) or high-voltage electric current [9,15,25]. Moreover, the duration of the electrical exposure may affect the outcome. A no-let-go exposure situation, involving involuntary tetanic muscle contractions in the hands induced by the alternating current frequency, may leave the victim unable to loosen their grip around a current conductor. This may prolong the exposure by several seconds, thereby increasing the harm to the body tissue. Such a situation is also psychologically traumatic [9,14,15]. Kelley et al. [9] observed that the risk of developing major depression or post-traumatic stress disorder (PTSD) was higher after a no-let-go exposure. However, being knocked away from the current source, indicating a short exposure duration, did not increase the risk of developing such symptoms.

Individual background characteristics, such as age or education of the victims and physical or psychiatric health before the accident may predict long-term health [9,14,26–28]. *Acute psychological reactions* to electrical accidents have been studied as possible predictors of various outcomes. Kelley et al. [9] observed a higher risk of developing major depression or PTSD in victims who experienced altered states of consciousness during the accident. Unconsciousness related to the accident was also associated with an increased incidence of PTSD. Hahn-Ketter et al. [2] concluded that early emotional sequelae largely predicted poor outcomes 4 years after an EI. A recent study by Thomée et al. found that both emotional responses at the time of the accident and health complaints after the accident constituted important indications for the subsequent medical and psychological follow-ups [29].

Finally, the *initial acute severity of the injury* has been suggested as a possible predictor of various long-term health effects after EIs. This includes confusion or amnesia regarding the event, nervous system injury or cardiac arrest, dysrhythmias, or vascular abnormalities, deviant acute or subacute laboratory examination results, and hospitalization or other health follow-ups in the acute phase [9,12,14,15,25–27].

Thus, in addition to various aspects of the electrical exposure and individual characteristics, both acute symptoms and reactions to the exposure [29] and medical treatment in the acute phase immediately after an accident [30] may influence the long-term health outcomes after electrical accidents [31]. However, only a few systematic follow-up studies [9,29,32] have combined these factors when addressing their predictive significance for long-term health after EIs.

Accordingly, in the present study, we sought to combine these factors in the analyzes. Furthermore, while short-term EI symptoms and other risk factors for long-term health outcomes have been studied in *patients* [12], some recent register-based studies have investigated such risk factors in *non-patient* samples selected strictly by exposure. However, non-patient *clinical* study designs allow more detailed descriptions of both exposure and acute symptoms and supplement register-based studies. Thus, we decided to perform a non-patient *clinical* study to analyze the predictors of long-term health after electrical accidents.

We hypothesized that several factors associated with the accident may predict the long-term health effects.

2. Aim

The present study aimed to determine and combine the accident characteristics, acute-phase psychological or nervous system reactions and symptoms, and hospitalization experiences as possible predictors associated with subjective general health ≥ 2 years after low-voltage electrical accidents.

3. Methods

3.1. Study design and setting

This was a retrospective cross-sectional study. Electricians in the south-eastern region of Norway who had experienced electrical accidents involving exposure to low-voltage alternating current during the period 1994–2001 were invited between 2002 and 2003 to participate in a 2003 follow-up health examination at the Norwegian National Institute of Occupational Health.

They were identified from a registry of electrical accidents reported to the Norwegian Directorate for Civil Protection. Reporting such an accident to this registry immediately after it has occurred is mandatory, thereby making it the most complete register of electrical accidents available.

The accident reports include the date and year of the accident; name and age of the victim; facts about the accident site; description of activity preceding the accident; description of the electrical installation including electric current and voltage; and description of the current pathway through the body or current arc injury.

3.2. Inclusion criteria and exposure

Accident reports from the registry were reviewed by the project leader. Male electricians who were subjected to 240–400 V low-voltage alternating current electrical accidents ≥ 2 years before the follow-up health examination, with either current arc exposure or passage of current through the body, were eligible for this study. All participants were included based on exposure characteristics alone.

3.3. Participants and sample size

A total of 147 electricians fulfilled the criteria for inclusion and constituted the study sample. Of these, 119 electricians were identified by address and invited to participate, and 89 electricians (74.8%) accepted to participate in the study (Fig. 1). The follow-up health examination occurred at a mean of 3.9 years (SD = 1.4, range = 2–9) after injury.

3.4. Comparison groups

The study sample was stratified and compared according to the *type of exposure*, to identify exposure-based acute reaction profile differences, and according to the *general health outcome*, to detect trends in acute reaction incidence as a function of general health at follow-up.

3.4.1. *Exposure stratification*

Based on information from the registry, the participants were stratified into the following three exposure groups, which were analyzed separately [9]: a current arc accident group with no passage of electric current through the body (N = 34) and two groups reporting an accident with the passage of electric current through the body, either in a “no-let-go” exposure situation (N = 35) or without such muscle contractions (“let-go” exposure; N = 20).

At examination, the mean ages of the electricians reporting current arc (N = 34), no-let-go (N = 35) and let-go (N = 20) accidents were 38.8 years (SD = 12.2, range = 21–59), 34.0 years (SD = 10.5, range = 21–57) and 38.7 years (SD = 10.3, range = 21–63), respectively.

The proportion of electric shocks with the passage of current through the body (61.8%) relative to current arc accidents (38.2%) among the participants was comparable to that among those who declined participation (56.7% vs. 43.3%).

To validate the exposure information provided in the registry, the participants at the 2003 follow-up health examination retrospectively described the *current type and voltage* of the accident, perceived *duration of the exposure*, most probable *current pathway through the body*, and *surface area* and

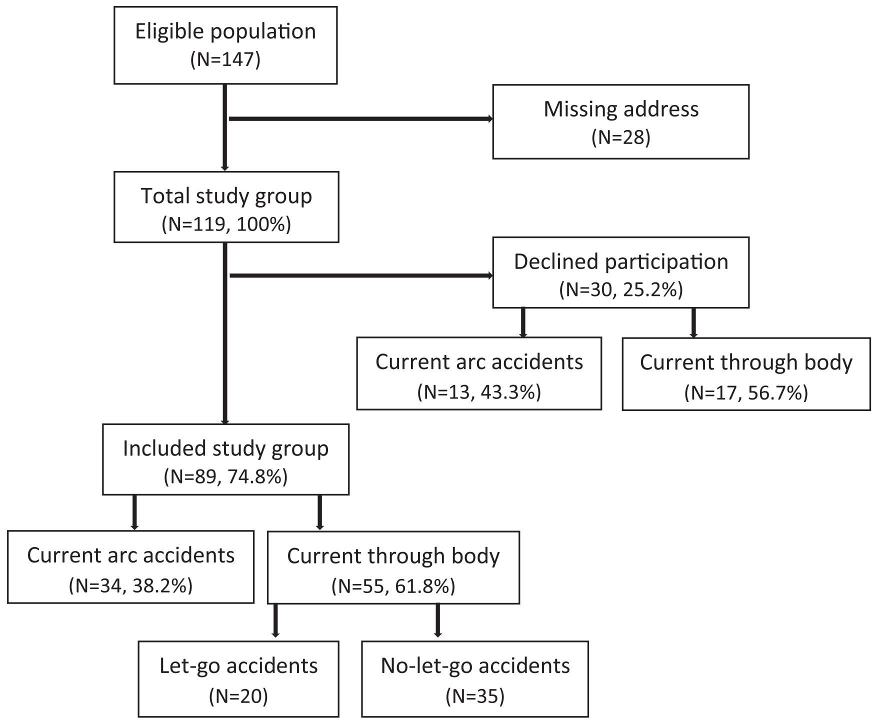

Fig. 1 – Male electricians involved in low voltage alternate current electric accidents reported to the Directorate for Civil Protection, eastern region of Southern Norway 1994–2001.

moisture in the contact points between the conductor and body in a supplementary exposure assessment. The original group allocation according to the exposure was supported and maintained based on this information.

3.4.2. *Classification of general health*

Each participating electrician rated their *current* subjective general health at the follow-up examination, by responding to a single-item visual analog scale (VAS) question. The response on a 10 cm line was transformed into a score ranging from 0 (extremely poor) to 100 (extremely good) [10,33].

The score was used to allocate the total study sample into three equal-sized outcome subgroups unevenly distributed in the three exposure-based groups, depending on whether their current general health was rated as poor (VAS score = 14–47, general health score [GHS] = 1), intermediate (VAS score = 48–57, GHS = 2) or good (VAS score = 58–73, GHS = 3) (Fig. 2). This score was the main health outcome indicator of

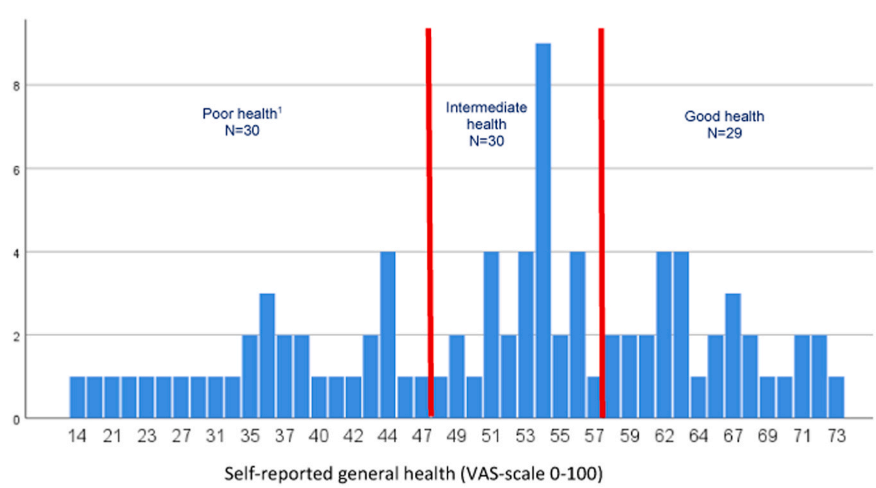

Fig. 2 – Distribution of general health at follow-up using a VAS-scale (0–100), among male electricians involved in low voltage alternate current electric accidents reported to the Directorate for Civil Protection, eastern region of Southern Norway 1994–2001 (N = 89). [1] General health index: 14–47 (poor), 48–57 (intermediate), 58–73 (good), respectively.

Table 1 – Characteristics and accident-related health of the accident group at follow-up (N = 89).

	Current arc accident, N = 34			Current through the body, N = 55					
				Let-go exposure, N = 20			No-let-go exposure, N = 35		
General health[a] →	Poor N = 12	Intermediate N = 10	Good N = 12	Poor N = 8	Intermediate N = 3	Good N = 9	Poor N = 10	Intermediate N = 17	Good N = 8
Years since accident[b]	4.3 (1.2)	3.9 (1.3)	3.4 (1.2)	4.1 (1.4)	2.3 (0.6)	3.1 (1.1)	4.6 (1.8)	4.1 (1.7)	3.8 (1.2)
Age at examination[b]	44.9 (13.2)	38.0 (11.9)	33.3 (9.2)	41.9 (4.7)	47.0 (14.2)	33.1 (10.6)	33.0 (7.2)	35.0 (11.5)	33.3 (13.0)
General health[a,b]	36.6 (7.2)	52.9 (2.1)	63.8 (4.6)	34.9 (8.6)	52.7 (4.5)	65.6 (3.9)	32.8 (11.7)	53.3 (2.1)	66.3 (5.2)
In work at examination[c]	11 (91.7)	10 (100.0)	12 (100.0)	6 (77.0)	2 (66.7)	9 (100.0)	9 (90.0)	15 (88.2)	7 (87.5)
Reduced ability to work[c]	2 (16.7)	1 (10.0)	1 (8.3)	1 (12.5)	–	1 (11.1)	4 (40.0)	2 (11.8)	1 (12.5)
Health problems[c,d]	7 (58.3)	5 (50.0)	2 (16.7)	3 (37.5)	1 (33.3)	1 (11.1)	7 (70.0)	7 (41.2)	3 (37.5)
-Muscular[c,d]	2 (16.7)	1 (10.0)	–	2 (25.0)	1 (33.3)	1 (11.1)	4 (40.0)	5 (29.4)	1 (12.5)
-Skin[c,d]	3 (25.0)	2 (20.0)	2 (16.7)	–	–	–	2 (20.0)	1 (5.9)	1 (12.5)
-Psychological[c,d]	1 (8.3)	–	–	1 (12.5)	–	–	1 (10.0)	–	–
-Eyes, Hearing, teeth[c,d]	1 (8.3)	2 (20.0)	–	–	–	–	–	1 (5.9)	1 (12.5)

[a] Self-rated general health at examination, scale 0 (extremely poor) to 100 (extremely good), stratified into the General health-score: 1 = poor health (index 14–47), 2 = intermediate health (index 48–57), 3 = good health (index 58–73).
[b] Mean (SD).
[c] N (%).
[d] Self-reported health problems at the examination, attributed to the accident.

self-reported general health in our study, rather than specific long-term symptomatology.

Mean general health index at the follow-up health examination was 51.0 (SD = 12.7, range = 23–72), 50.4 (SD = 14.1, range = 14–73) and 51.4 (SD = 15.7, range = 21–71) in the current arc accident, no-let-go and let-go groups, respectively. The no-let-go group with *poor* self-rated general health scored slightly lower than the others, while a larger *proportion* of the let-go group reported poor self-rated general health (40.0%) than those in the current arc accidents (35.3%) and no-let-go groups (28.6%) (Table 1).

The participants also described specific *persisting* symptoms that were attributed to the accident in the questionnaire, and they underwent a clinical examination (not presented here). Specific health problems attributed to the accident by the participants at the examination (N = 36, 40.4% of 89 participants) included primarily muscular problems/pain (N = 17, 19.1%), which were more prevalent after experiencing current flow through the body, and skin problems (N = 11, 12.3%), which were more prevalent in the current arc accident group. Moreover, reduced ability to work (N = 13, 14.6%) was primarily due to accident-related localized hand, arm, shoulder, or neck problems (N = 9, 10.1%) (Table 1).

3.5. *Endpoints: associations between acute injury, injury symptoms and injury reactions, and follow-up GHS*

We analyzed the association between *retrospectively reported acute injury, injury symptoms and injury reactions* during and shortly after the accidents, and *subjective general health* at the follow-up examination. The three exposure groups were analyzed separately and compared.

Information regarding the accident characteristics (*loud noise*, *intense light* and *material damage*) (Table 2), acute injury (*burn injury* to the *face*, *neck*, *hands*, *arms* and *upper parts of the body*) (Appendix 1, Table A), acute reactions (*unconsciousness* and *confusion*) (Table 2) and initial medical treatment (*hospitalization* and *outpatient consultations*) (Appendix 1, Table B) was obtained using yes/no type questions (no = 0; yes = 1). The medical treatment was also described as the number of inpatient treatment days or outpatient consultations.

Questions regarding the remaining variables covering acute reactions (Table 2) were answered using a scoring scale between 0 (none at all) and 6 (severe). Before further analyzes, each response was converted into a dichotomous variable, where scores from 0 to 3 and 4 to 6 represented no/mild and pronounced symptoms, respectively.

Within each of the exposure groups, these true or converted dichotomous variables covering *exposure*, *circumstances at the moment of the accident*, *acute reactions* and *initial medical treatment* were then associated with the categorized *follow-up GHS* [10,33].

This enabled comparison of acute reaction profiles between the exposure groups, in addition to multivariate analyses to identify the most important variables associated with the *follow-up GHS* within each exposure group.

3.6. *Ethic*

Each of the invited participants was informed that participation was voluntary. Those who were willing to participate provided written informed consent and were informed that they could withdraw from the study at any time and have their information removed on request. We applied no invasive methods. After the data preparation, the data files were depersonalized, so that the participants could only be identified by a participant number in combination with a name/number key stored at a different place than the data.

Table 2 – Acute circumstances and reactions of the current arc and low voltage AC accidents (N = 89).

	Current arc accident N = 34	Current through the body (total) N = 55	P[a]	Let-go current N = 20	No-let-go current N = 35	P[a]
Loud noise (N, %)	30 (88.2%)	4 (7.3%)	< 0.001	2 (10.0%)	2 (5.7%)	n.s.
Intense light/heat	34 (100%)	3 (5.5%)	< 0.001	2 (10.0%)	1 (2.9%)	n.s.
Burning clothes	13 (38.2%)	0 (0.0%)	< 0.001	–	–	–
Material damage	23 (67.6%)	4 (7.3%)	< 0.001	–	4 (11.4%)	n.s.
Thrown backwards	16 (47.1%)	13 (24.1%)[b]	0.036	5 (25.0%)	8 (23.5%)[c]	n.s.
Anger, rage	16 (47.1%)	9 (16.7%)[b]	0.003	6 (30.0%)	3 (8.8%)[c]	n.s.
Pain	29 (85.3%)	24 (44.4%)[b]	< 0.001	5 (25.0%)	19 (55.9%)[c]	0.046
Prolonged exposure duration[d]	9 (26.5%)	28 (50.9%)	0.028	4 (20.0%)	24 (68.6%)	0.001
Shock	13 (38.2%)	22 (40.0%)	n.s.	6 (30.0%)	14 (45.7%)	n.s.
Anxiety	9 (26.5%)	14 (25.9%)[b]	n.s.	2 (10.0%)	12 (35.3%)[c]	n.s.
Palpitations/tachycardia	19 (55.9%)	33 (60.0%)	n.s.	10 (50.0%)	23 (65.7%)	n.s.
Panic	4 (11.8%)	14 (25.5%)	n.s.	0 (0.0%)	14 (40.5%)	0.001
Confusion	24 (70.6%)	39 (70.9%)	n.s.	10 (50.0%)	29 (82.9%)	0.014
Fear of death	3 (8.8%)	16 (29.1%)	0.032	2 (10.0%)	14 (40.0%)	0.029
Unconsciousness[d]	2 (5.9%)	13 (24.1%)[b]	0.040	1 (5.0%)	12 (35.3%)[c]	0.019
Incapacitated, exhaustion	8 (23.5%)	33 (60.0%)	0.001	7 (35.0%)	26 (74.3%)	0.009
Numbness	10 (29.4%)	29 (52.7%)	0.047	6 (30.0%)	23 (65.7%)	0.013
Headache	4 (11.8%)	16 (29.1%)	n.s.	6 (30.0%)	10 (28.6%)	n.s.
Dizziness	4 (11.8%)	29 (52.7%)	< 0.001	8 (40.0%)	21 (60.0%)	n.s.
Nausea	2 (5.9%)	16 (29.1%)	0.013	6 (30.0%)	10 (28.6%)	n.s.
Apathy	4 (11.8%)	25 (45.5%)	0.001	8 (40.0%)	17 (48.6%)	n.s.
Muscle tension	4 (11.8%)	29 (52.7%)	< 0.001	7 (35.0%)	22 (62.9%)	n.s.
Chest pain	1 (2.9%)	13 (23.6%)	0.014	2 (10.0%)	11 (31.4%)	n.s.
Irregular heartbeat	1 (2.9%)	18 (32.7%)	0.001	6 (30.0%)	12 (34.3%)	n.s.
Sweating	5 (15.2%)[e]	20 (36.4%)	0.050	5 (25.0%)	15 (42.9%)	n.s.
Symptom duration ≥ 1 day	17 (50.0%)	27 (49.1%)	n.s.	10 (50.0%)	17 (48.6%)	n.s.
Frightening experience	30 (88.2%)	42 (76.4%)	n.s.	13 (65.0%)	29 (82.9%)	n.s.
Relief	11 (32.4%)	24 (44.4%)[b]	n.s.	4 (20.0%)	20 (58.8%)[c]	0.010
Good acute health care[d]	28 (82.4%)	33 (61.1%)[b]	n.s.	12 (63.2%)[f]	21 (60.0%)	n.s.
Repeated thoughts	23 (67.6%)	32 (58.2%)	n.s.	12 (60.0%)	20 (57.1%)	n.s.

[a] Chi square, Fisher exact test, p, sig. < 0.05.
[b] N = 54.
[c] N = 34.
[d] Self-reported subjective evaluation.
[e] N = 33.
[f] N = 19.

The study procedures were in accordance with the approval of project S-02063 by the Regional Committee for Medical and Health Research Ethics (REK south-east), 10 June 2002, and the Norwegian Data Protection Authority approval (2003/544-2), 13 March 2003.

3.7. *Statistical analysis*

The IBM SPSS Statistics (version 22.0 for Windows; IBM SPSS, Armonk, NY, USA) was used for data analysis.

A two-sided Fisher's exact test was used for comparison of the prevalence of the dichotomous outcome variables describing accident characteristics and reactions in connection with the accident in the three exposure groups (Table 2).

For detection of trends in proportions of single acute reactions and long-term general health, we compared the following: (a) each exposure group reporting *poor* follow-up general health (≤ 47, scale 0–100) with the remaining groups reporting *intermediate* (48–57) or *good* (≥ 58) health; (b) each exposure group reporting *poor* follow-up general health with the group reporting *good* health; and (c) those reporting *poor* or *intermediate* follow-up general health with the group reporting *good* health (see footnote c, Tables 3 and 4). We used a two-sided Fisher's exact test in these univariate analyses comparing acute symptom prevalence in the three health outcome subgroups *within* each of the three exposure groups (Tables 3 and 4).

In a supplementary analysis of outcome-dependent symptom incidence trends, *ordinal logistic regression* analyses were used to study the associations between acute symptom prevalence and *follow-up GHS* (see footnote d, Tables 3 and 4).

Multivariate linear regression analyses of groups (Appendix 2) of independent variables, or visual inspection of the proportion of single symptoms in the health outcome subgroups, were used in the selection of important independent variables for a final analyses of associations between the acute variables and *follow-up GHS* in each of the three exposure groups.

For comparison of the selected multiple independent variables covering accident situations and acute reactions with the dependent GHS variable, backward variable elimination linear regression, with exclusion criterion p ≥ 0.060,

Table 3 – Electrical accident acute reactions[a] and general health[b] at follow-up (N = 89).

	Current arc accident, N = 34					Current through the body, N = 55				
General health score[b] → *Acute reactions*	Poor N = 12	Intermediate N = 10	Good N = 12	P[c]	P[d]	Poor N = 18	Intermediate N = 20	Good N = 17	P[c]	P[d]
Psychological reactions										
Shock	2 (16.7)	4 (40.0)	7 (58.3)	–	0.039	9 (50.0)	8 (40.0)	5 (29.4)	–	–
Panic	1 (8.3)	2 (20.0)	1 (8.3)	–	–	4 (22.2)	6 (30.0)	4 (23.5)	–	–
Fear of death	3 (25.0)	–	–	a	–	7 (38.9)	4 (20.0)	5 (29.4)	–	–
Prolonged exposure[e]	1 (8.3)	5 (50.0)	3 (25.0)	–	–	9 (50.0)	11 (55.0)	8 (47.1)	–	–
Anxiety	1 (8.3)	3 (30.0)	5 (41.7)	–	–	5 (29.4)	7 (35.0)	2 (11.8)	–	–
Anger, rage	5 (41.7)	6 (60.0)	5 (41.7)	–	–	3 (17.6)	3 (15.0)	3 (17.6)	–	–
Apathy	1 (8.3)	3 (30.0)	–	–	–	11 (61.1)	10 (50.0)	4 (23.5)	b,c	0.028
Neurological symptoms							–			
Unconsciousness[e]	1 (8.3)	–	1 (8.3)	–	–	4 (22.2)	6 (30.0)	3 (17.6)	–	–
Confused	9 (75.0)	7 (70.0)	8 (66.7)	–	–	16 (88.9)	15 (75.0)	8 (47.1)	b,c	0.007
Immediately after accident:										
Neurological symptoms										
Numbness/insensibility	5 (41.7)	4 (40.0)	1 (8.3)	–	–	10 (55.6)	14 (70.0)	5 (29.4)	c	–
Incapacitated/debilitated	4 (33.3)	3 (30.0)	1 (8.3)	–	–	10 (55.6)	14 (70.0)	9 (52.9)	–	–
Dizziness	2 (16.7)	1 (10.0)	1 (8.3)	–	–	13 (72.2)	10 (50.0)	6 (35.3)	b	0.029
Nausea	–	1 (10.0)	1 (8.3)	–	–	6 (33.3)	6 (30.0)	4 (23.5)	–	–
Headache	1 (8.3)	2 (20.0)	1 (8.3)	–	–	9 (50.0)	5 (25.0)	2 (11.8)	a,b	0.013
Pain										
Muscle tension	3 (25.0)	1 (10.0)	–	–	–	10 (55.6)	11 (55.0)	8 (47.1)	–	–
Pain (unspecified)	10 (83.3)	9 (90.0)	10 (83.3)	–	–	9 (52.9)	11 (55.0)	4 (23.5)	c	–
Chest symptoms										
Chest pain	–	1 (10.0)	–	–	–	4 (22.2)	5 (25.0)	4 (23.5)	–	–
Palpitations/tachycardia	4 (33.3)	8 (80.0)	7 (58.3)	–	–	13 (72.2)	13 (65.0)	7 (41.2)	–	–
Irregular heartbeat	–	1 (10.0)	–	–	–	7 (38.9)	9 (45.0)	2 (11.8)	c	–
Other symptoms										
Sweating	–	3 (30.0)	2 (18.2)	–	–	7 (38.9)	10 (50.0)	3 (17.6)	–	–
Chills	3 (25.0)	4 (40.0)	2 (18.2)	–	–	4 (22.2)	6 (30.0)	4 (23.5)	–	–
Symptom duration ≥ 1 day	8 (66.7)	7 (70.0)	2 (16.7)	–	0.015	11 (61.1)	11 (55.0)	5 (29.4)		
Frightening experience	11(91.7)	9 (90.0)	10 (83.3)	–	–	15 (88.3)	18 (90.0)	9 (52.9)	c	0.025
Relief	8 (66.7)	2 (20.0)	1 (8.3)	a,b	0.003	6 (35.3)	11 (55.0)	7 (41.2)	–	–
Good acute health care[e]	11 (91.7)	8 (80.0)	9 (75.0)	–	–	9 (52.9)	13 (65.0)	11 (64.7)	–	–
Repeated thoughts	9 (75.0)	7 (70.0)	7 (58.3)	–	–	13 (72.2)	13 (65.0)	6 (35.3)	b,c	0.027

[a] Proportion reporting pronounced acute reactions, cut-off ≥ 4, scale 0 (not at all) to 6 (to a large extent)
[b] Self-rated general health at examination, scale 0 (poor) to 100 (good), stratified into the General health-score: 1 = poor health (index 14–47), 2 = intermediate health (index 48–57), 3 = good health (index 58–73).
[c] Sub-group chi-square p-values, – = n.s., sig. < 0.05: a = $P_{1 \text{ vs. } 2,3}$, b = $P_{1 \text{ vs. } 3}$, c = $P_{1,2 \text{ vs. } 3}$, where $_1$ = Poor, $_2$ = Intermediate, $_3$ = Good health.
[d] Ordinal logistic regression, – = n.s., sig. < 0.05.
[e] Self-reported subjective evaluation.

was used in the final multivariate analysis (Table 5) to identify the most important acute variables associated with impaired long-term general health in each of the three exposure groups.

For describing the non-dichotomous background measures (Appendix 1, Table B), arithmetic mean and SD were calculated.

4. Results

The results indicated *a common pattern of psychological reactions* to a traumatic incident, wherein many participants considered the accident as profoundly *frightening*, including experiencing a *shock*, *palpitations/tachycardia* and to some extent *anxiety reactions* at the moment of the accident, with no significant exposure group differences (Table 2).

However, the *accident circumstances* were significantly different in the current arc and passage of current exposure categories. The *current arc accidents* were primarily characterized by a sudden loud noise, strong flash of light and intense heat.

Moreover, typical exposure group differences were observed for the *acute symptom profile* (Table 2). Acute *eye injuries* (52.9%); *pain in the eyes* (55.9%); *difficulties in seeing* (64.7%); and *burn injuries* particularly *on the face* (52.9%), *neck* (32.4%), *hands* (82.4%) and *forearm(s)* (47.1%) were reported almost entirely after *current arc* accidents (Appendix 1, Table A), and *pain* was also significantly more common in that group (Table 2). A larger proportion of this group reported acute effects

Table 4 – Acute reactions[a] in electrical accidents with current through the body, and general health[b] at follow-up (N = 55).

	Current through the body									
	Let-go exposure, N = 20					No-let-go exposure, N = 35				
General health score[b] → *Acute reactions*	Poor$_1$ N = 8	Intermediate$_2$ N = 3	Good$_3$ N = 9	P[c]	P[d]	Poor N = 10	Intermediate N = 17	Good N = 8	P[c]	P[d]
Psychological reactions										
Shock	3 (37.5)	2 (66.7)	1 (11.1)	–	–	6 (60.0)	6 (35.3)	4 (50.0)	–	–
Panic	–	–	–	–	–	4 (40.0)	6 (35.3)	4 (50.0)	–	–
Fear of death	–	–	2 (22.2)	–	–	7 (70.0)	4 (23.5)	3 (37.5)	–	–
Prolonged exposure[e]	2 (25.0)	–	2 (22.2)	–	–	7 (70.0)	11 (64.7)	6 (75.0)	–	–
Anxiety	1 (12.5)	–	1 (11.1)	–	–	4 (44.4)[9]	7 (41.2)	1 (12.5)	–	–
Anger, rage	2 (25.0)	1 (33.3)	3 (33.3)	–	–	1 (11.1)[9]	2 (11.8)	–	–	–
Apathy	4 (50.0)	1 (33.3)	3 (33.3)	–	–	7 (70.0)	9 (52.9)	1 (12.5)	b,c	0.021
Neurological symptoms										
Unconsciousness[e]	–	–	1 (11.1)	–	–	4 (40.0)	6 (37.5)	2 (25.0)	–	–
Confused	6 (75.0)	2 (66.7)	2 (22.2)	–	0.032	10(100.0)	13 (76.5)	6 (75.0)	–	–
Immediately after accident: Neurological symptoms										
Numbness/insensibility	2 (25.0)	2 (66.7)	2 (22.2)	–	–	8 (80.0)	12 (70.6)	3 (37.5)	–	–
Incapacitated/debilitated	2 (25.0)	1 (33.3)	4 (44.4)	–	–	8 (80.0)	13 (76.5)	5 (62.5)	–	–
Dizziness	5 (62.5)	1 (33.3)	2 (22.2)	–	–	8 (80.0)	9 (52.9)	4 (50.0)	–	–
Nausea	2 (25.0)	1 (33.3)	3 (33.3)	–	–	4 (40.0)	5 (29.4)	1 (12.5)	–	–
Headache	3 (37.5)	1 (33.3)	2 (22.2)	–	–	6 (60.0)	4 (23.5)	–	a,b	0.006
Pain										
Muscle tension	3 (37.5)	–	4 (44.4)	–	–	7 (70.0)	11 (64.7)	4 (50.0)	–	–
Pain (unspecified)	3 (37.5)	1 (33.3)	1 (11.1)	–	–	6 (66.7)	10 (58.8)	3 (37.5)	–	–
Chest symptoms										
Chest pain	–	1 (33.3)	1 (11.1)	–	–	4 (40.0)	4 (23.5)	3 (37.5)	–	–
Palpitations/tachycardia	4 (50.0)	3 (100.0)	3 (33.3)	–	–	9 (90.0)	10 (58.8)	4 (50.0)	–	–
Irregular heartbeat	3 (37.5)	2 (66.7)	1 (11.1)	–	–	4 (40.0)	7 (41.2)	1 (12.5)	–	–
Other symptoms										
Sweating	1 (12.5)	3 (100.0)	1 (11.1)	–	–	6 (60.0)	7 (41.2)	2 (25.0)	–	–
Chills	–	2 (66.7)	2 (22.2)	–	–	4 (40.0)	4 (23.5)	2 (25.0)	–	–
Symptom duration ≥ 1 day	5 (62.5)	2 (66.7)	3 (33.3)			6 (60.0)	9 (53.0)	2 (25.0)		
Frightening accident	7 (87.5)	3 (100.0)	3 (33.3)	b, c	0.022	8 (80.0)	15 (88.2)	6 (75.0)	–	–
Relief	2 (25.0)	–	2 (22.2)	–	–	4 (44.4)	11 (64.7)	5 (62.5)	–	–
Good acute health care[e]	5 (71.4)	2 (66.7)	5 (55.6)	–	–	4 (40.0)	11 (64.7)	6 (75.0)	–	–
Repeated thoughts	7 (87.5)	2 (66.7)	3 (33.3)	b	0.029	6 (60.0)	11 (64.7)	3 (37.5)	–	–

[a] Proportion reporting pronounced acute reactions, cut-off ≥ 4, scale 0 (not at all) to 6 (to a large extent).
[b] Self-rated general health at examination, scale 0 (poor) to 100 (good), stratified into the General health-score: 1 = poor health (index 14–47), 2 = intermediate health (index 48–57), 3 = good health (index 58–73).
[c] Sub-group chi-square p-values, – = n.s., sig. < 0.05: a = $P_{1\ vs.\ 2,3}$, b = $P_{1\ vs.\ 3}$, c = $P_{1,2\ vs.\ 3}$., where $_1$ = Poor, $_2$ = Intermediate, $_3$ = Good health.
[d] Ordinal logistic regression, – = n.s., sig. < 0.05.
[e] Self-reported subjective evaluation.

lasting > 1 day (26.5%) than the *let-go* (10.0%) and *no-let-go accident groups* (11.4%), maybe because of the *burn injuries* (data not shown in tables).

The total group (comprising both the let-go and no-let-go accident groups) exposed to the *passage of current through the body* more often reported acute *muscle tension*, *chest pain*, *irregular heartbeat*, *apathy*, *dizziness*, *nausea*, *sweating* and *headache* than the current arc group.

The no-let-go group generally reported higher incidences of acute symptoms than the let-go group. *Acute psychological reactions* were more common after a no-let-go accident, as was *confusion*, *panic* and *fear of death* at the moment of the accident or immediately afterwards. Specifically, *immediate unconsciousness* was almost entirely restricted to the no-let-go accidents (Table 2).

Due to these observations, we found it appropriate to maintain our original study design of analyzing the associations between acute or subacute reactions and *long-term general health* in both the current arc and passage of current exposure groups separately (Table 3) and to analyze similar associations in the let-go and no-let-go passage of current groups separately (Table 4).

We observed some differential outcome-associated trends in acute reactions and symptom incidences, particularly between the current arc accident and total passage of current groups (Table 3).

Table 5 – Impact of individual background, exposure characteristics, acute psychological reactions and health symptoms, and acute-phase health follow-up and examinations, for current health, 3.9 years after an occupational injury involving electricity: Linear regression[a].

		Regression-coefficients[b]												R^2	Model
Raw scores	Constant[c]	Years since accident		Frightening accident		Relief		Confusion		Numbness		Headache			p
Exposure type[d]	B[c]	B	p	B	p	B	p	B	p	B	p	B	p		
Current through body	3.14	-0.16	0.017	-0.48	0.040	–	–	–	–	–	–	-0.56	0.013	0.25	0.002
No-let-go exposure	3.20	-0.17	0.018	–	–	–	–	–	–	-0.53	0.029	-0.66	0.008	0.38	0.002
Let-go exposure	2.50	–	–	–	–	–	–	-0.90	0.029	–	–	–	–	0.24	0.029
Current arc accidents	2.30	–	–	–	–	-0.94	0.001	–	–	–	–	–	–	0.27	0.001

[a] Backwards linear regression. Dependent variable: General health score (1-poor to 3-good). Independent variables: Age at examination, years since the accident, dichotomous variables (0–1): burn injuries in hands, burn injuries in neck, no-let-go experience (not when let-go and no-let-go are analyzed separately), thrown backwards by explosion, horizontal current path yes/no (not current arc sub-group), one or more electrical accidents, sub-acute apathy, acute confusion, numbness, dizziness, headache, irregular heartbeats immediately after the accident, duration of acute symptoms, accident experienced as profoundly frightening, and relief after accident, included in total-group model for all accident groups.
[b] Unstandardized B-Coefficient shown for variables included in the final model, exclusion criterion $p \geq 0.060$, reflecting impact on the general health score (1-poor to 3 good).
[c] $p < 0.001$.
[d] Current through body (N = 55), No-let-go exposure (N = 35), Let-go exposure (N = 20), Current arc accidents (N = 34).

A tendency for a shorter *duration* of acute reactions was observed in all exposure groups when reporting good general health at the follow-up examination; however, it was statistically significant only for the *current arc accident group*. The five *passage of current victims* who both reported good health at follow-up and indicated acute reactions the first day "or longer" (Table 3), all had acute reactions lasting for the first day only (data not shown in table).

Within the *current arc accident group*, none of the *variables* listed in Table 2 characterizing the exposure, i.e., loud noise and strong light or heat, were statistically associated with impaired long-term general health. No statistically significant distribution tendencies of *acute burns* and eye injuries across the self-reported general health groups were observed at the follow-up in this exposure group (Appendix 1, Table A). Acute psychological reactions were not significantly more common in the group reporting poor general health than in those reporting better general health 4 years after injury (Table 3).

Acute confusion was common in all exposure groups. Moreover, it was significantly more common in the *total* passage of current exposure group when reporting *poor* or *intermediate* follow-up general health than *good* follow-up general health (Table 3).

We also observed that the no-let-go accident victims who *did not* report acute confusion or acute reactions beyond the first hour after the incident were more likely to report *good general health* 4 years later (Table 4).

In the *total* passage of current exposure group, acute-phase reactions, such as *dizziness*, *apathy* or *pronounced headache* during or immediately after the accident, were significantly more common when reporting *poor health* than *good health* 4 years after injury, while *numbness* and *irregular heartbeat* were more frequent when reporting *poor* or *intermediate* health at follow-up than *good* health at follow-up (Table 3). This is also the case for *apathy* or *headache* during or immediately after the accident in the *no-let-go group*. Although acute *unconsciousness* was almost exclusively restricted to this group, it was not associated with impaired long-term general health (Table 4).

Victims in the *no-let-go group* who experienced *acute fear of death* (70.0%) more often reported *poor health* 4 years after injury than those in the other health groups (≤ 37.5%) (Tables 3 and 4).

Not judging the accident as *extremely frightening* after a *let-go accident* was significantly associated with good follow-up general health. In this health group, 33.3% of the victims experienced the accident as *extremely frightening*. In all other accident health groups, ≥ 75% of the victims experienced the accident as extremely frightening (Tables 3 and 4).

We had an a priori hypothesis that *acute-phase medical treatment and follow-up* could affect the long-term health outcomes after an accident. Thus, we sought to determine the predictive significance of acute treatment for long-term health. A substantial proportion of the accident victims (55.1%) were hospitalized after acute on-site follow-up. In addition to the initial hospitalization, 27.0% of the victims reported multiple outpatient follow-up consultations, while 28.1% reported none or one outpatient follow-up consultation. Of those who were not hospitalized, 29.2% of the victims reported one follow-up consultation and 11.2% reported multiple outpatient follow-up consultations. Only 4.5% of the total sample received no medical treatment (Appendix 1, Table B).

A higher proportion of victims in the current arc accident group than those in the total passage of current group were hospitalized or sent to a medical emergency ward, and in many cases, they had *multiple* outpatient follow-up consultations. The no-let-go accident victims were most often hospitalized with *up to one* outpatient consultation only. The current arc accident victims who reported *poor* general health at the follow-up were *most often hospitalized* in the acute phase. However, the reverse was the case for the no-let-go accident victims, and those with *good* general health at the follow-up examination were *most often hospitalized* in the acute phase.

The final part of the analysis was aimed at combining the relevant independent accident variables covering *background*, *exposure*, *acute reactions and health symptoms, and acute health follow-up* in a multivariate backward linear regression analysis model, to identify the most robust markers of general health at the follow-up examination using the *follow-up GHS (1 [poor] to 3 [good])* as the dependent variable (Table 5).

We selected and included the independent variables that we considered most representative *within each factor* in this final multivariate analysis. The selection process comprised of inspection of symptom frequency and profile in the univariate analyses and intra-factor multivariate regression analyses, covering the following aspects: (1) relevant individual background, (2) exposure characteristics, (3) acute psychological reactions and health symptoms, (4) duration of acute symptoms, (5) acute-phase medical treatment and follow-up, (6) retrospective subjective rating of acute health care and accident severity, and (7) current health complaints attributed to the accident (Tables 1–4). The details are described below and in Appendix 2.

(1) *Individual background variables included age at examination and time since the accident only, because the participants were all occupationally active skilled electricians at the time of the accident, relatively healthy and comprised a homogenous group regarding their background.*
(2) Several *exposure variables were relevant for multivariate analysis. Accident type was used as a criterion for stratified analysis. We considered the self-reported current pathway among those who had experienced the passage of current through the body as horizontal from hand to hand (N = 45) vs. not horizontal (N = 10), including vertical or local pathway or contact via the head. The variable "being thrown backward by the exposure" may indicate a supplementary current pathway through the legs in the horizontal passage of current accident group. Whether the victims were thrown backward or had a no-let-go experience may also reflect the exposure duration.* We also considered self-reported information regarding the *surface area* and *moisture of the contact point* between the conductor and body in the passage of current accident groups, theoretically indicating the *conducting properties* of this interface (Appendix 1, Table C). Finally, we considered the *number of previous electrical accidents*. At the examination, 60 (67.4%) participants reported only the accident registered by the Directorate for Civil Protection, 20 (22.5%) reported two accidents, and nine (10.1%) reported > 2 accidents. In a separate introductory regression analysis, the *current pathway*, *surface area* or *moisture* of the contact point with the conductor, the *no-let-go experience*, whether the victim was *thrown backward* by the exposure, and the *total number of electrical accidents (1, 2, or > 2 accidents)* did not contribute significantly to the *long-term general health*. In the total group exposed to the passage of current through the body (N = 55), exposure was associated with *selected acute reactions* as follows; Acute pronounced numbness (R^2 = 0.18, p = 0.006) was associated with the *no-let-go experience* (β = 0.5, p = 0.002) and having experienced a *higher number of electrical accidents* (β = 0.2, p = 0.044). Acute confusion (R^2 = 0.12, p = 0.011) was associated with the *no-let-go experience* (β = 0.3, p = 0.011). Acute unconsciousness (R^2 = 0.22, p = 0.006) was associated with the *no-let-go experience* (β = 0.3, p = 0.026), being *thrown backward* at the moment of the accident (β = 0.3, p = 0.033), and a *horizontal current pathway* through the body (β = − 0.3, p = 0.048). Based on these observations, we included the four exposure variables *no-let-go experience*, *being thrown backward*, *current pathway* and *number of accidents* in a final multivariate regression analysis.
(3) The *acute reaction variables included (based on the analyzes in* Table 3) *apathy, confusion, numbness, dizziness, headache and irregular heartbeat. Symptoms indicating differences between the three accident subtypes* (Table 2), but no probable exposure–outcome association (Tables 3 and 4), were not included because the analysis aimed to identify the possible predictors in the acute phase. On analyzing the current arc accidents (N = 34) separately, *general health (R^2 = 0.28, p = 0.018) was found to be influenced by burn injuries on the face (β = 0.68, p = 0.037), neck (β = − 0.93, 0.009) and hands (β = − 0.78, p = 0.033). Visual inspection of the variable burn injury on the face indicated a limited impact on the outcome of general health. Burn injuries on the neck and hands were included in the final multivariate analysis.*
(4) *Duration of the acute reactions, whether lasting for ≤ 1 h or > 1 day after the accident, was included.*
(5) *Medical follow-up variables included admission to hospital, acute emergency ward or outpatient health follow-up. None of the following three variables contributed significantly to the long-term general health when included in an introductory regression analysis (0–1; 0 = no, 1 = yes): Total acute medical follow-up, outpatient medical follow-up only and hospital follow-up with or without additional outpatient follow-up. Thus, medical follow-up was not included in the final regression analysis.*
(6) The patients' retrospective rating of acute health care and how the accident was evaluated and reacted to in the aftermath of the accident may influence the later reporting of other aspects of the accident. The following four variables (0–1) were included in introductory regression analysis: Perception of how frightening the accident was in retrospect, relief immediately after the accident, evaluation of acute health care, and whether repeated thoughts of what happened had been pronounced. In the regression analysis, *acute pronounced relief after the accident (β = − 0.9, p = 0.001) was associated with*

impaired general health ($R^2 = 0.27$, $p = 0.001$) in the current arc accident group (N = 34). Describing the accident as profoundly frightening ($\beta = -1.0$, $p = 0.026$) was associated with impaired general health (R2 = 0.26, $p = 0.026$) in the let-go accident group (N = 20). Describing repeated thoughts of the accident ($\beta = -0.4$, $p = 0.052$) was only close to significantly associated with impaired general health (R2 = 0.07, $p = 0.052$) in the total passage of current group. Based on these observations, the two variables considering the accident as profoundly frightening and reporting strong relief after the accident were included in the final total multivariate regression analysis.

(7) The following five variables (0–1) indicating the number and type of current symptoms attributed to the accident were included in an introductory regression analysis: Total number of patients reporting the specified health *problems attributed to the accident (skin problems only, muscular problems, psychological problems or sensory problems). Neither in the current arc accident group (N = 34) nor the total passage of current group (N = 55), including the subgroups separately, did any of the factors indicating health problems attributed to the accident contribute significantly to the follow-up general health. Thus, they were not included in the final regression analysis.*

To summarize, the multivariate backward regression analysis combining various aspects of an electrical accident with a possible impact on the follow-up general health included the following independent background variables: *age*, *time since the accident*, and the exposure variables (*no-let-go experience, being thrown backward, current pathway and number of accidents*). The included acute symptoms were *apathy*, *confusion*, *numbness*, *dizziness*, *headache* and *irregular heartbeat*. Burn injuries on the *neck* and *hands* and *the duration of the acute reactions* were also included. In addition, *considering the accident as profoundly frightening* and *strong relief after the accident* were included. The dependent variable was the *follow-up GHS*. As far as possible and relevant, we applied similar independent variables in the analyzes of all three exposure groups, to be able to detect group-specific differential symptom patterns (see footnote a, Table 5).

The *final* multivariate equations indicated that primarily acute pronounced *headache* and *bodily numbness* may predict impaired general health at follow-up after a no-let-go accident. The variable *years since the accident* was also negatively associated with general health at follow-up in this group. *Emotional reactions* were negatively associated with general health, but the expression of these reactions to the accidents varied across the exposure groups (Table 5).

5. Discussion

The most important acute marker associated with impaired general health at the follow-up examination was *acute pronounced headache* after an electrical accident with the passage of current through the body. If the accident also included a no-let-go experience, then *pronounced bodily numbness* was also an important marker (Table 5).

Univariate analyses also indicated that after the passage of current through the body, *apathy*, *confusion*, *dizziness*, and *irregular heartbeat* were more frequent *acute reactions* when the general health was impaired at the follow-up health examination (Table 3). For clinical purposes, because the dichotomous variables were converted from a 0–6 scoring scale, only the original scores between 4 and 6 were considered to represent pronounced symptoms.

These *nervous system* and *chest symptoms* may well be related to nervous system involvement during the passage of current in deeper tissues, particularly during a *no-let-go exposure* compared with the more superficial exposure of the current arc accident victims with burn injuries and *acute pain*. However, *acute burn injuries* (Appendix 1, Table A) are not negatively associated with the long-term health outcome in this latter exposure group (Table 3). This differential acute reaction pattern between the exposure groups justifies the exposure-specific analyses regarding acute-phase long-term health predictors.

Some common acute reactions (Table 2) were not associated with long-term general health. *Acute confusion* immediately after the accident occurred in approximately 70% of our total sample, except for the let-go accident victims who reported *good* health at follow-up. *Shock*, *anxiety and palpitations* were also experienced by a considerable proportion of the accident victims, with no significant exposure group differentiation. The expected additional impact of the no-let-go accidents was limited regarding these *acute* emotional reactions. In accordance with our *crude* findings that the *mean* general health rating is comparable in the groups with or without a no-let-go experience, Pliskin [27] found that long-term somatic and nervous symptoms do not vary as a function of the exposure parameters. Thomée [29] also observed that a no-let-go experience was not significantly associated with the *long-term* psychological and cognitive outcomes.

However, Thomée and Jakobsson [34] concluded that the no-let-go experience was a particularly stressful part of an accident, while Kelley et al. [9] found that the no-let-go experience was a risk factor for PTSD and major depression. These observations are qualitatively compatible with our more detailed findings from the acute phase, wherein the acute psychological reactions of *panic* and *fear of death* were significantly more common in the no-let-go group than in the let-go group, as were the nervous system acute symptoms of *unconsciousness*, *confusion*, *numbness* and *exhaustion*. The observations made by Kelley et al. [9] that in addition to the no-let-go experience, *unconsciousness* or *altered states of consciousness* during an electrical accident were associated with increased incidence of PTSD or major depression are interesting, because in our sample, *unconsciousness* occurred almost only in the case of a no-let-go exposure.

Taken together, these observations indicate that a no-let-go experience is more severe both psychologically and in terms of the nervous system acute reactions. Our exposure stratification approach may have made the differences in severity more evident, demonstrating that a no-let-go exposure situation, when accompanied by severe acute nervous system reactions, is a *risk factor for impaired long-term general health*.

The multivariate analysis identified the core acute background variables or reactions associated with long-term general health in our study sample. The variable *years since* *the accident* was negatively associated with long-term general health at the follow-up in the total passage of current group, and particularly in the no-let-go subgroup. This factor is, by definition, not an acute marker of long-term health. The impact of time since the accident can be interpreted as due to a reporting bias. However, the accidents were not included because they were remembered by the victims, but because they were reported immediately after their occurrence. Furthermore, time since the accident was not associated with long-term general health in the current arc accident group, thereby making this a differential rather than a general factor of importance. The importance of time since the accident might also appear to be more significant if the older accidents were more severe. However, this is not likely the case in the present study because the included accidents had occurred within an 8-year period with relatively stable working conditions and level of reporting. Finally, several studies considered the possibility of both latency time between the exposure and development of symptoms and gradually developing symptoms [12,14,15,20]. If these factors were important, then time since the accident could be expected to be negatively associated with the follow-up general health, which we observed in our multivariate analyses.

In *the multivariate regression analysis,* we found that the *no-let-go accident victims* who experienced *pronounced headaches* and *bodily numbness* immediately after the accident were at the risk of developing long-term impaired health. A possible embedded impact of the traumatic experiences may have been masked by these nervous system symptoms in the multivariate analyses, which is noteworthy considering that two recent studies indicated the impact of acute emotional responses for long-term health or coping after EIs [2,29].

While the *nervous system reactions* were the most important reported *acute* symptoms in the *passage of current group*, the specific symptoms attributed to the accident at the *follow-up* examination in the no-let-go group were *musculoskeletal symptoms* (Table 1). In addition to neurological and psychological symptoms, musculoskeletal symptoms have been described as common long-term health effects after electrical accidents in a previous study [17].

Several additional acute reactions were *indicators*, or predictors, for *long-term impaired general health* because they were differentially distributed across the groups of self-reported long-term health *within* each exposure category (Tables 3 and 4).

Duration, in addition to *type*, of acute reactions may be associated with long-term health. The portion of each exposure group reporting *good health at follow-up* tended to include a higher proportion of participants who had reported the duration of acute reactions as only a few minutes or the first hour after the accident. Thus, the short *duration of acute reactions* could be a predictor for long-term subjective *good* general health. Our data also indicated that a duration of acute reactions *longer* than the first day may alert clinicians regarding the possibility of *impaired* long-term general health after an electrical accident. Thomée [29], in a study of electricians who had experienced an electrical accident, also observed that the reporting of initial health complaints lasting for > 1 week after the accident was associated with reduced mental well-being at a follow-up examination that took place at a median of 6.8 years after the accident.

The impact of hospital admission in the acute phase for long-term health is more complicated to evaluate. Moreover, the cause of admission may be of importance. More frequent acute-phase hospital admissions of the no-let-go victims who reported the best general health at the follow-up examination could imply that the most severe accident victims who reported *poor general health* at the follow-up examination were not necessarily hospitalized. Alternatively, early hospitalization may have improved future general health. However, the association between short duration of acute effects and good general health at the follow-up does not indicate the latter possibility.

The pattern of acute symptoms after a current arc accident with more frequent acute hospital admissions and skin problems at the follow-up for those with poor health at the follow-up examination may indicate that *the acute severity of the burn itself* may have impacted the general health at the follow-up of this group. This is also supported by a recent study that reported that after electrical accidents, burns were a significant factor associated with > 24-h hospitalization [35].

It may be useful to summarize not only the factors associated with *poor* but also *good* long-term health after an EI. In the present study, those who had experienced an electrical accident including the *passage of current through the body* had better prospects if they did not experience the accident as extremely frightening, experience confusion or apathy immediately after the accident, or experience extreme pain, bodily numbness, irregular heartbeat, or severe headaches in connection with the accident.

5.1. *Methodological considerations*

A major *strength* of the present study was that its clinically-oriented design enabled a detailed description of exposure and acute reactions, and thus supplemented purely register-based study designs [21,36]. A need for a more thorough exposure description in studies of EI has been emphasized by Chauveau [20]. Another *strength* was that the exposure information was collected from a registry containing data collected at the time of the accident.

We also consider the introduction of a modified case–-control aspect into an otherwise cross-sectional study design as a strength. When we stratified the victims into three general health groups in each exposure group, we made visible the variability of outcomes after a certain exposure. Ultimately, we could study whether the selected accident circumstances and acute reactions could be associated with, or be acute predictors of, long-term general health.

We preferred using a continuous VAS to avoid categorizing the respondents into categories that they might find difficult to choose between, and for statistical reasons, because an answer marked on a point anywhere on a 10-cm line represents a true continuous response.

Such a single-item questionnaire is as sensitive as multiple-item questionnaires to cover the perceived global health without further specifications [37] with good reliability and validity, and it is widely used [10]. A single-item questionnaire has been found to reflect chronic rather than acute health and exclude temporary fluctuations in perceived health; for instance, those due to infections such as colds or flu [38,39]. How people judge their general health is also associated with both mortality [40] and daily-life coping [41]. We found it useful to include such a general health single-item question that is both multidimensional in nature and with predictive implications regarding daily-life coping.

A general major *limitation* of the present study was that a cross-sectional study design does not reveal causal relationships, but rather reveals unspecified associations between the independent and dependent variables.

Another limitation was that information regarding both *acute injury, initial medical treatment, symptoms and reactions* as well as assessment of *general health at follow-up* was collected using a common questionnaire at the 2003 follow-up health examination. Accordingly, differential misclassification is a risk, especially regarding questions covering conditions, acute reactions or symptoms at the time of the accident. Moreover, recall bias may be of importance in the present study, i.e. poor health at the follow-up examination may result in a higher reporting of acute symptoms.

However, although acute nervous system reactions were associated with health at follow-up in the present study, symptoms *other than* those arising from the nervous system were reported as the cause of impaired health at follow-up. Thus, the connection between acute reactions and health at follow-up was not obvious to the participants.

Furthermore, because inclusion in the study and allocation into three exposure categories were based on exposure information registered at the time of the accident, a differential rather than a general symptom profile in our three exposure groups suggests that joint collection methods cannot explain all observations.

There are sources of bias related to the accident register. Reporting of electrical accidents to the Directorate for Civil Protection is mandatory, but only partly practised. Due to this underreporting [1], possible regional variations in accident-reporting may limit the representativity of our study sample. In addition, companies with well-developed accident and incident reporting routines are over-represented in this register. Such companies also report the less severe accidents, thereby leading to lower *estimates of health problems*. Conversely, different reporting practices regarding the more severe and the less severe accidents may be present. Electricians with acute health problems after an electrical accident may more often report them, thereby resulting in *elevated estimates of health problems*. Thus, it cannot be easily concluded how this affects our observed exposure–effect associations.

The accidents and health surveys in the present study occurred up to 2003. Since then, and until 2015, the annual reporting of electrical accidents in Norway has become 10 times higher. This trend is also visible in other countries [3] and can reduce the estimates of health problems and affect the symptom profile. For instance, while a study by Arnoldo [42] reported an age distribution and symptom levels comparable to those in the present study, more recent studies examining patients admitted to hospitals in the period 2011–2016 [43] reported both lower age and acute symptom prevalence. This may reflect the increased reporting of less severe accidents in recent years, particularly by younger workers. This assumption is supported by the present study finding that the accident group with the seemingly least severe exposure, the let-go accident group, was smaller than the seemingly more severe current arc and no-let-go accident groups and comprised the highest proportion of victims reporting *poor* general health at follow-up. Thus, the symptom estimates for the let-go accident group of the present study may be higher than those based on more recent study samples [35] recruited from registers that are similar to ours, due to a possible differential inclusion in the exposure groups. However, although more recent study samples consisted of an increased proportion of less dramatic electrical accidents compared with our study sample, our observations remain a relevant reference for more recently collected data, because sample selections such as ours are still embedded in the more recent study samples.

The comparable proportion of accident types among those who did participate in the study compared with those who did not, in addition to the distribution of self-reported general health in the total study sample, does not indicate any obvious symptom bias in the mere process of recruiting participants in the present study.

The *exposure characteristics* were primarily collected at the time of the accident, but Supplementary information was collected retrospectively at the follow-up examination. The information was consistent across both these platforms.

The present study was also an exploratory study of possible exposure–effect modifiers in the case of *low-voltage alternating current* electrical accidents [42]. Based on the preliminary regression analyses of possible exposure variables, and because electricity may cause injury through various mechanisms [44,45], we also included the following four exposure variables in final multivariate regression analysis: *no-let-go experience*, *current pathway*, *being thrown backward* and *number of accidents a victim experienced*.

Identifying the *current pathway* through the body is complicated because the subjective current pathway may not cover what really happened. Tetanic contractions in both hands may partly confirm a horizontal pathway between the two hands, while similar *acute muscle contractions* in the legs may throw the victim backward, indirectly indicating a *supplementary vertical* current pathway, even though only a horizontal pathway is described. However, in current arc accidents, an explosion-like situation, with a blast effect, can also throw the victim away from the source [9,15].

The observed or subjective *exposure duration* is vulnerable to skewed memory, even shortly after accidents, and is considered of low validity, with a tendency of overestimation of the duration [46,47]. Thus, we instead included in the analyzes the no-let-go variable, as an indicator of exposure duration beyond a momentary exposure.

As electrical accidents are rather common, many participants in the present study group had experienced *additional severe accidents* before the reported accident or in the time interval between the reported accident and the health examinations. This may *blur or reduce intergroup differences* in the follow-up health outcomes, because the current health status may depend on the reported accident, other accidents, or other conditions. However, the introductory regression analysis did not indicate that the number of accidents contributed significantly to the prediction of long-term general health.

Due to the non-causal cross-sectional study design and the multifactorial properties of the general health status, it remains to be concluded whether the observed associations between acute reactions and general health reflect symptoms related to the nervous system or muscular, psychological or other long-term symptoms. Future studies should further specify the health challenges beyond the concept of general health. For this, prospective study designs including clinical populations and data from acute-phase medical reports will be warranted.

A practical implication of the present study is that it demonstrates the signs and symptoms in patients that should alert the clinician in the acute phase after an electrical accident, regarding the risk of developing long-term effects.

6. Conclusion

After a low-voltage electrical accident including the passage of current through the body, acute-phase nervous system reactions of pronounced headache and bodily numbness after a no-let-go exposure and acute confusion after a let-go exposure were the most important predictors that were negatively associated with the subjective general health ≥ 2 years after the electrical accident. The short duration of acute reactions may be a predictor for long-term subjective good general health. Combining the information regarding specific exposure and acute reactions facilitated the identification of factors associated with long-term general health.

CRediT authorship contribution statement

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by **LOG**, **KBV** and **ØS**. The first draft of the manuscript was written by **LOG**. All authors, **LOG**, **KBV**, **BB**, **LPB** and **ØS**, critically reviewed and commented on and revised previous versions of the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

None.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.burns.2022.04.007.

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