Construction workers’ falls through roofs: 
Fatal versus serious injuries

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Abstract

Problem: The study examined risk factors for fatal versus serious injuries of construction workers’ falls through roofs. Method: Fatal injury falls (N=10) were matched against serious injury falls (N=10), and descriptive analyses were carried out retrospectively of investigation reports. Results: Fatal injuries occurred predominantly on farms, in the afternoon, and without the use of passive personal fall protective equipment (PPFPE; safety net, lifeline, etc.). In contrast, serious injuries disproportionately occurred in the morning hours, and were likely due to decreased risk perceptions and less safe behavior, possibly as the result of the greater use of PPFPE. Summary: Risk factors for fatal and serious roof fall injury incidents differ in terms of farm/nonfarm location, time of day, and use of PPFPE. Impact on industry: Occupational injury incident surveillance systems need to collect data systematically regarding the status and role of personal protective equipment (PPE).

Keywords: Occupation; Risk factor; Falls from heights; Personal protective equipment; Descriptive analysis

1. Introduction

The building and construction industry (hereafter referred to as ‘construction’) is a dynamic and hazardous industry, making it both unique and challenging to study. This is
due to the diverse and complex nature of work tasks, trades, and environments, as well as
the temporary and transitory nature of construction workplaces and the construction
workforce (e.g., Ringen, Englund, Welch, Weeks, & Seegal, 1995; Ringen, Seegal, &
Englund, 1995; ). Studies from many countries show that preventing falls from heights in
construction is necessary to prevent fatal injuries. Kines (2001) shows that this focus is
also relevant for reported serious and minor lost-time injuries.

The purpose of this study is to examine whether risk factors for fatal and serious injury
incidents were identical for construction workers’ falls from heights. Heinrich (1931/1986)
proposed an iceberg model of occupational accident frequency and injury severity, in
which minor and major accidents form the visible, but relatively small tip of the iceberg of
occupational accident processes, whereas the overwhelming majority of processes do not
result in injury (i.e., the submerged base and body of the iceberg). Heinrich initially found
evidence to support an identical causation hypothesis (i.e., risk factors involved in fatal
and nonfatal injury incidents are the same as in incidents resulting in no injury). However,
later studies by Hale and Hale (1970), Heinrich, Peterson, and Roos (1980), and Peterson
(1971/1987) found evidence supporting the different accident causation hypothesis (i.e.,
risk factors involved in fatal and nonfatal injury incidents versus noninjurious incidents,
were dissimilar). Lozada-Larsen and Laughery (1987) found, in their study of 7131 minor
and major injuries in a manufacturing company over a 5-year period, that individual
accident variables support the identical causation hypothesis, whereas combinations/
sequences of accident variables support the different causation hypothesis. The purpose
of this study is related to the identical accident/injury causation hypothesis. However, it
goes beyond immediate causes by looking at the role of underlying risk factors such as
attention to safety (safety culture)—where causal relationships to injury incidents are not
as direct. For example, the absence (or presence) of a safety net under a roof will not
directly cause a worker to fall, but it may be a risk factor, in that it can affect the way a
worker behaves.

A few studies in the literature have looked, in more depth, into factors that may affect
injury incident rates and injury outcome. Prather, Crisera & Fidell’s (1975) study of 123
volunteer roofers in California with high (N=63) and low (N=60) injury incident rates,
found that there were no significant differences between the two groups in terms of their
behavioral patterns (workers, job layout, work conditions), psychological assessments
(personality, attitude, and adjustment), and performance measurements (vision, reaction
time, decision-making). More recent studies, including those of Salminen, Saari, Saarela,
and Rasanen (1992) and Saloniemi and Oksanen (1998) provided support for the
differential accident/injury causation hypothesis. Salminen et al.’s prospective, in-depth,
cross-industry study found that accident factors related to work habits accounted for a
greater proportion of nonfatal injury incidents, whereas organizational factors and
handling of materials played a greater role in fatal injury incidents. In addition, they
found that fatally injured workers were less likely to have been under supervision than
nonfatally injured workers.

The present study is unique in comparing fatal and nonfatal injury incidents in that it
focuses narrowly on one specific type of male injury incident in one specific industry, as
opposed to earlier studies that often compared injuries across gender, industries, and/or
types of injury incidents.
2. Method

The study is based on reported male fatal and lost-time injury elevation fall incidents in the Danish construction industry. The injury incidents were reported to the National Working Environment Authority in Denmark during the 7-year period 1993–1999. During this period, 19 fatal fall injury incidents occurred resulting in 20 fatal injuries. During the same time period, 1048 serious lost-time-injury falls were reported (Kines, 2001). Serious injuries were predefined by the National Working Environment Authority as lost-time-injury-incidents resulting in amputations, bone fractures, and/or injury to extensive parts of the body.

In this study, the 19 fatal fall injury incidents were matched with 19 serious fall injury incidents, and comparisons were made of the risk factors involved. Matching was carried out according to the following prioritized list of coded factors in the occupational injury incident (accident) database at the National Working Environment Authority in Denmark:
(a) type of elevation fall (e.g., fall from, fall through); (b) working surface (e.g., ladder, scaffold, roof); (c) construction branch and occupation; (d) mechanism of the incident (e.g., roof tiles, roof sheets, and skylights/roof lights); (e) injuring mechanism (e.g., cement floor); (f) age (within ±10 years); (g) skill level (e.g., skilled, unskilled); (h) number of employees in the company; (i) type of employment; (j) activity at the time of the incident; and, finally, (k) weekday.

All available reports collected by the Danish Working Environment Authority regarding their investigations of each of the 38 incidents, which often included the police’s investigation reports, were requested from the administrative authorities. A number of a priori hypotheses were proposed for this study regarding possible risk factors that might be mentioned in the reports. These hypotheses stated that injury severity outcome was independent of the time of day of the injury incident, as well as the status of active/primary and passive/secondary personal fall protective equipment. Active or primary personal fall protection equipment in this study refers to measures that physically prevent a fall to a lower level from occurring (e.g., crawling boards/planks). Passive or secondary personal fall prevention equipment on the other hand, inhibits or minimizes injury after an already initiated fall to a lower level (e.g., safety nets, lifelines) (Bobick, Stanevich, Pizatella, Keane, & Smith, 1994).

Alternative hypotheses were proposed that stated that injury incident severity outcome was dependent on the height of the fall, the injured part(s) of the body, the farm versus nonfarm location of the incident, and whether the worker was working alone. Farm/nonfarm and working alone were hypothesized as influencing injury outcome, as critical medical attention would likely take longer to arrive at farms. In addition, working on farms was thought to influence negatively the construction workers’ use of personal protective equipment, as the possibility of detection by working-environment authorities would be relatively smaller compared to work carried out on nonfarm locations.

Finally, it was expected that the quality and quantity of data would differ for fatal and serious injury falls, in that fatal injury incidents would be investigated to a greater degree than serious injury incidents. This naturally limited the number of hypotheses tested in the study, as underlying factors such as wage practices (e.g., piecework) and organizational
factors were expected to be mentioned to a lesser degree in the incidents resulting in only serious injury.

Descriptive analyses of the reports were carried out by the author. In addition to the possible risk factors recorded in the database and those mentioned in the hypotheses for this study, the descriptive data provided, in some cases, additional possible risk factors including weather conditions, blood alcohol concentrations, and medical conditions.

After descriptively analyzing the available data for the 19 fatal and 19 serious injury fall incidents, a decision was made to focus on the 10 fatal injury falls where a worker fell through roofing materials (e.g., roof tiles/sheets/lights, wooden support beams) or a hole in a roof. This decision was taken partly so as to have as comparable data as possible, and due to the fact that not all the investigation reports for falls involving other work surfaces were available, as they were still being handled in court. The 10 fatal injury falls through roofs were then analyzed together with their matched cases of 10 serious injury roof falls.

3. Results

3.1. Matching results

The results of some of the matching variables and risk factors for the 10 fatal and 10 serious injury falls through roofs are shown in Table 1. There were eight carpentry trade workers, one electrician, and one nonskilled worker involved in the 10 fatal injury falls. The matching procedure resulted in precisely the same distribution of professions involved in serious injury falls, as well as whether the carpenters were registered as master carpenters, carpenters, assistant carpenters, or carpenter trainees. A paired $t$ test of the mean of the age difference of the two groups (0.8 years) was not significantly different.

3.2. Study material

As expected, the quantity and quality of information in the reports from the Danish Working Environment Authority and the police reports of the 10 fatal and 10 serious injury falls through roofs varied greatly from case to case. All 10 of the fatal injury roof falls were, to some degree, investigated by the Working Environment Authority, and eight were investigated by the police. However, only four of the matched serious injury falls were investigated by the police, and six by the Working Environment Authority. In four serious injury fall cases, where neither the police nor the Working Environment Authority investigated the injury incident, only the lost-time-injury-incident report form was used.

The descriptive analyses revealed that some of the categories of data regarding the falls through roofs could not be filled in, as they seldom were mentioned in the reports (e.g., weather conditions and blood alcohol concentration, particularly for the serious injury falls). On the other hand, the status of passive and active personal fall protective equipment was often mentioned in the reports.
### Table 1
Matched cases of fatal and serious occupational injuries from elevation falls through roofs—Danish construction workers (1993 – 1999)

<table>
<thead>
<tr>
<th>Case</th>
<th>Injury</th>
<th>Age</th>
<th>Profession</th>
<th>Location</th>
<th>Time of day</th>
<th>Active fall-through prevention measure (c=confirmed)</th>
<th>Passive fall injury prevention measure (c=confirmed)</th>
<th>Height of fall</th>
<th>Injury</th>
<th>Contact surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fatal</td>
<td>53</td>
<td>C-master</td>
<td>Farm building</td>
<td>10:15</td>
<td>Planks—c</td>
<td>None—c</td>
<td>6.6</td>
<td>SF+BI</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Fatal</td>
<td>48</td>
<td>C-master</td>
<td>House—urban</td>
<td>10:45</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td>vertebra</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fatal</td>
<td>41</td>
<td>C-master</td>
<td>House—urban</td>
<td>13:00</td>
<td>None</td>
<td>None</td>
<td>8</td>
<td>BI</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fatal</td>
<td>36</td>
<td>C-master</td>
<td>Building—urban</td>
<td>11:00</td>
<td>None</td>
<td>None</td>
<td>6</td>
<td>SF+BI</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Fatal</td>
<td>28</td>
<td>C-assistant</td>
<td>House—urban</td>
<td>14:00</td>
<td>None</td>
<td>Net—c</td>
<td>7</td>
<td>SF+BI</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Fatal</td>
<td>44</td>
<td>C-assistant</td>
<td>Farm building</td>
<td>15:30</td>
<td>None</td>
<td>Scaffolding—c</td>
<td>5</td>
<td>Liver+bleeding</td>
<td>TT+CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fatal</td>
<td>37</td>
<td>C-assistant</td>
<td>Farm building</td>
<td>11:45</td>
<td>Planks—c</td>
<td>None</td>
<td>4</td>
<td>back+hand</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fatal</td>
<td>33</td>
<td>C-trainee</td>
<td>Farm building</td>
<td>8:00</td>
<td>None</td>
<td>Net—c</td>
<td>8.5</td>
<td>spine+leg</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Fatal</td>
<td>49</td>
<td>Nonskilled</td>
<td>Building—urban</td>
<td>15:15</td>
<td>None</td>
<td>Lifeline—c</td>
<td>4</td>
<td>SF+BI</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Fatal</td>
<td>40</td>
<td>Electrician</td>
<td>Building—urban</td>
<td>10:45</td>
<td>Planks—c</td>
<td>None</td>
<td>4.5</td>
<td>hand+leg</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BI=brain injury, CF=cement floor, F=floor, RP=roof panel, SF=skull fracture, TT=tractor tire.
3.3. Risk factors

3.3.1. Work situation

All 10 fatal injury falls occurred while the worker was working on the roof of a building, seven of which were on farms. The 10 serious injury falls involved a greater variety of structures (i.e., houses, farm and warehouse buildings, and at a mill). Four of the 10 fatal injury falls occurred to workers from a county that accounted for only approximately 5% of the national construction workforce. Nine and seven of the fatal and serious injury falls, respectively, occurred in counties that accounted for only approximately 38% of the national construction workforce.

In 6 of the 10 fatal injury roof falls, the worker was alone when he fell through the roof. In some cases, his colleague had temporarily gone elsewhere. However, in the remaining four cases, the workers’ colleagues were very close when the fatal injury fall occurred. Nine of the 10 fatal injury falls occurred during the middle of the work process, while the 10th one occurred after mounting the last roof sheet. There was not enough information in the serious injury falls to determine whether or not the workers had been working alone at the time of their fall, nor at what point in the work process their falls occurred.

In 8 of the 10 fatal injury falls, carpenters were replacing roof sheets, which often were made of asbestos cement fiber materials. This fragile roofing material is normally not designed to safely support the weight of a person, but depends on the thickness and profile of the sheets, the span between the support beams, the type, number, position, and quality of the fixings, the design of the supporting structure, and the age of the material (Health and Safety Executive [HSE], 1999). In the two other fatal injury falls through roofs, an electrician fell through a large opening in a roof, and a carpenter fell while hammering wooden support beams to a roof structure.

In 6 of the 10 serious injury falls, the workers were replacing and repairing roofing material, including one case where a worker was installing insulation. In two other serious injury cases, the worker was in the process of establishing fall safety measures: one of the workers was on his way up the roof to attach a lifeline to a permanent fixture, and the other worker was carrying wooden planks that he was to mount on the roof as a work platform. In another case, an apparent volunteer worker had, on his own initiative, ventured up onto an unfamiliar, snow covered, flat rooftop, and inadvertently stepped-on and penetrated a flat, snow-covered skylight panel. This latter case was the only one of the 20 cases where an environmental factor (snow) was confirmed to have played a contributory role in an injury incident.

3.3.2. Time of fall injury incidents

It was hypothesized a priori that a greater proportion of the construction workers’ fall incidents would have occurred in the hours between 7:00 a.m. and 12:59 p.m., and a lesser proportion in the hours between 1:00 p.m. and 6:59 p.m. Danish construction workers typically start work early in the day (at approximately 7:00 a.m.), and finish their lunch break no later than 1:00 p.m. Therefore, a majority of their working hours are before 1:00 p.m. The results for serious injury falls confirmed the abovementioned hypothesis, not just in terms of the 10 serious injury falls through
roofs, where eight occurred in the morning hours and two in the afternoon hours, but also in terms of all serious and minor injury elevation falls in construction and in all economic sectors combined during the period 1993–1999 (Table 2). The proportions of serious and minor fall injury incidents during 3-h time periods were almost identical. Surprisingly though, a majority of fatal injury falls occurred in the afternoon hours. This was seen not just in the 10 fatal injury roof falls (6 of the 10), but also for the 19 and 60 known times of day of fatal elevation falls in construction and all economic sectors combined, respectively. The majority of known times of fatal injury elevation falls in all economic sectors (42%), as well as in construction (42%), and the 10 cases focused on in this study (50%)—occurred in the 3-h time period between 1:00 p.m. and 3:59 p.m.

The odds ratio (OR) for a fatal compared to a serious elevation fall injury incident occurring in the afternoon time period was statistically significant (chi-square test) in all industrial sectors combined (OR=2.53; \( P<.001 \)). The ORs were borderline significant for fatal compared to a serious elevation fall injury incident in the construction industry (OR=2.29; \( P<.07 \)), as well as for the 10 fatal and 10 serious elevation fall injury incidents in this study (OR=6; \( P<.07 \)).

In order to further verify the credibility of the results regarding times of day of fatal and nonfatal injuries, analyses were carried out on known times of day of Swedish elevation fall injury incidents in all economic sectors combined and in construction in the period 1993–1999 (Börje Bengtsson, Swedish Work Environment Authority, personal communication February 28, 2001). Similar patterns to the Danish data were also found in the Swedish data. The majority of fatal elevation fall injury incidents (\( N=55 \) and \( N=20 \), all economic sectors and construction only, respectively) were again found in the afternoon time period 1:00 p.m.–6:59 p.m., whereas the majority of serious elevation fall injury incidents (\( N=5740 \) and \( N=1746 \), respectively) occurred in the morning time periods. For the Swedish data, the ORs for a fatal compared to a serious fall injury incident occurring in the afternoon time period were, however, not significant.

Table 2
Known time of day of male occupational fatal and lost-time-injury elevation falls in Denmark (1993–1999)

<table>
<thead>
<tr>
<th>Hour (24 hour clock)</th>
<th>All economic sectors (%)</th>
<th>Construction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal (( N=60 ))</td>
<td>Serious (( N=3354 ))</td>
</tr>
<tr>
<td>01:00–03:59</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>04:00–06:59</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>07:00–09:59</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>10:00–12:59</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>13:00–15:59</td>
<td>42</td>
<td>27</td>
</tr>
<tr>
<td>16:00–18:59</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>19:00–21:59</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>22:00–00:59</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>101a</td>
<td>101a</td>
</tr>
</tbody>
</table>

\( a \) Percentages do not add up to 100 due to rounding.
3.3.3. Status of personal fall protective equipment

In almost all the fatal injury falls through roofs where a colleague was present, the colleague mentioned to the investigating authorities that they had been very careful to step only on the roof sheets directly where there were wooden support beams underneath. This they could see by the mounting screws on the roof sheets. They all knew of the risks of stepping onto the middle of a roof sheet, yet often due to time and economic considerations, had often not bothered setting up any personal fall protection equipment. For all 20 cases in this study, the workers were performing work at heights that, according to work environment regulations, required the use of personal fall protection measures. The average fall height was approximately 5.8 m (range 4–8 m) for the 10 fatal injury falls, and approximately 4.4 m (range 2–8.5 m) for the 10 serious injury falls. A paired t test showed a borderline significant difference between the mean of the difference for heights of the fatal and serious injury falls (1.45 m; *P* < .09).

In the investigation materials, confirmation of the use of active fall-through and/or passive fall injury prevention measures was possible for all 10 fatal injury incidents, and 7 of the 10 serious injury incidents (Table 1). In the three serious injury cases where confirmation was not possible, it was assumed that no attention to fall prevention measures had been taken. The presence and use of active personal fall protection in the form of a working platform made of wooden planks/crawling boards secured on top of roof sheets was confirmed in two of the fatal injury cases and two of the serious injury cases. In spite of the use of crawling boards, in three cases, the workers fell through the roofs because they ventured off the crawling boards onto the roof sheets, and stepped on a sheet where it was not able to support the workers’ weight. In the fourth case, narrow and ineffectively short crawling boards tilted because they were not properly secured. The worker then lost his balance, trod onto and penetrated a roof sheet, and fell to his death.

The casual attitudes toward actively preventing falls and/or minimizing fall injuries were reflected in a typical comment of one of the workers as quoted by the investigating authorities: “that’s just the way one often does things in order to save time,” and in one of the workers’ employer’s comments regarding attention to safety: “They are, after all, adults. They knew what to do.”

Passive personal fall injury protection, in the form of safety nets, were strung up under the roofs in only 3 of the 20 incidents. In all three cases, the injured workers had helped to set the nets up themselves. In both a fatal injury and a serious injury fall, the net was strung up under the side of the roof that was being repaired at the time. In both cases, the workers ventured onto the other side of the roof, and when they fell through the roof sheets, there was no net to arrest their fall. In the third case, the worker had strung up a safety net under the roof, and was in the process of installing crawling boards. However, the net did not cover the entire underside of the roof, and when the worker penetrated the roof sheet, he bypassed the net and fell to the cement floor below. In a fourth case where passive personal fall injury protection was present, a worker, wearing a lifeline, was climbing up a roof to attach the lifeline to a permanent fixture, when he fell through the roof and seriously injured himself. In a fifth case, a worker fell through wooden support beams and bounced off the edge of a scaffolding tower that was placed under the roof so as to arrest an eventual fall, and the worker continued falling to the cement floor below, sustaining serious injuries. In total, 4 of the 10 seriously injured workers knew they had some form of
passive personal fall injury protection equipment (PPFPE), whereas this was the case in only 1 of the 10 fatally injured workers.

In only 1 of the 20 cases was there any mention in the reports of the use or presence of a hard-hat. Although hard-hat use is often mandatory for construction work, they are often not strapped on, which results in them falling off during a fall process.

### 3.3.4. Injuries

In almost all the fatal and serious injury elevation falls, the workers landed on a cement floor (Table 1), and 8 of the 10 fatally injured workers died within 2 hours of the fall. A contributing injury risk factor that appears to distinguish the fatal from the serious injury falls is that none of the seriously injured workers sustained notable head injuries, whereas for 9 of the 10 fatally injured workers, the medical examiner’s report determined the cause of death as resulting from a skull fracture and/or injury to the brain. In the serious injury falls, the workers instead suffered fractures to the spine, vertebra, shoulder, hip, lumbar, arm, hand, and/or leg.

### 3.3.5. Other factors

Medical/physiological factors appeared to contribute to at least one fatal fall injury. The fatal injury case, which is based on both eyewitness and autopsy reports, involved a worker suffering an alcohol-related abstinence seizure while working with a colleague on a roof. A conscious decision had been made, prior to starting work on the roof, not to string a safety net up, as the distance between the wooden support beams was so narrow that it was not likely that one could fall through them. Subsequently, when the worker suffered the seizure, he was not in any state to prevent himself from falling through the relatively narrow passage.

In two other cases involving fatal injury falls, the workers had been known to suffer from epileptic seizures and high blood pressure, respectively, but there was no evidence that these conditions contributed to their falls. Alcohol did not appear to play a contributory role in any of the fatal injury falls. However, alcohol analyses (blood/urine) were only carried out in four of the fatal injury cases, and the results of the analyses were only available in two of the cases. Only one serious injury case mentioned anything about alcohol, and in this case, the police judged the worker to have been sober.

### 4. Discussion

The main limitation of this study was, as expected, the lack of detailed information surrounding some of the serious injury elevation falls. These were investigated to a much lesser degree by work environment inspection authorities and the police. The results from this study should, therefore, be interpreted with caution and only as indicators of possible risk factors.

A number of studies of occupational injuries in construction industries in different countries have identified roofing, and roofers in particular, as having elevated risks of fatal falls from heights (e.g., Derr, Forst, Chen, & Conroy, 2001; Stern, Ruder & Chen, 2000; Janicak, 1998; Chen & Fosbroke, 1998; Ringen, Englund, et al., 1995; Ringen, Seegal, et
al., 1995; Robinson et al., 1995) and there has, more recently, been a focus on the different types of falls from heights. Several studies include limited descriptive analyses of data on falls through roofs (Bobick et al., 1994; Cloe, 1979; Copeland, 1989; Helmkamp & Lundstrom, 2000; McCann, 2000). Both Caldwell (1999) and Suruda, Fosbroke, and Bradee (1995) have, as in this study, found that roof falls often involved fragile roofing materials, such as asbestos cement sheets. The above studies, however, rarely mention the status or role of personal secondary/passive fall protection equipment.

The research question in this study was whether the risk factors for fatal and serious injury were identical. Almost all the injured workers in this study had experience working on roofs, and, when venturing onto the fragile roofing material, knew of the possibility of penetrating them. In the 10 fatal and 10 serious injury falls, the fall heights were all potentially fatal and the workers all landed on very hard surfaces—usually cement floors (Table 1). With the greater (borderline significant) fall heights in the fatal injury incidents, velocity at impact would generally have been greater, thus negatively affecting injury outcome. The types of injury differed, as none of the seriously injured workers suffered serious head injuries, whereas almost all the fatality-injured workers suffered skull fractures.

In almost all of the 20 cases in this study, the workers were working on slanted roofs. Therefore, it may be plausible that when they fell, it was not likely that they fell straight through the roofing material and landed on their feet. Rather, some form of bodily rotation occurred during the fall, such that the fatally injured workers to a greater degree may have landed headfirst. In addition to education, training, and enforcement to prevent falls from occurring, the results of, in particular, the fatal injuries, point to the need for strapped-on helmets. A possible solution could be lightweight bicycle-type helmets that are designed to take one (not repeated) blow.

The descriptive analyses of the circumstances surrounding the falls in this study have resulted in the identification of three risk factors that differentiate between whether a fall from a height was more likely to result in fatal injury as opposed to serious injury: (a) the time of day of the fall; (b) the status of passive personal fall protection equipment (PPFPE); and (c) the farm/nonfarm location of the workplace. The following is a discussion on all three factors, and the possible interaction between them in terms of risk perception, risk behavior, and injury outcome.

Unlike serious and minor injury falls, a disproportionate number of fatal fall injuries occurred in the afternoon hours, particularly between the hours of 1:00 p.m. and 3:59 p.m. This result, based on 10 fatal injury falls, was found to be credible for all elevation falls in construction and in all economic sectors of Denmark and Sweden. Working on slanted roofs made of fragile material, in which a slight misstep can result in fatal or nonfatal injury, is a task that requires a great deal of mental and physical energy throughout a working day. The disproportionate number of fatal injuries in the afternoon is thus likely explained by the interaction between increasing fatigue, and routine and/or time constraints later on in the daily work process, all of which are likely to negatively affect workers’ risk perceptions and behavior. In addition, fatigue is likely to affect negatively the workers’ reactions and reflexes when a fall has been initiated, such that injury outcome is more serious than if the worker had been more attentive and alert.

Worker risk perception and behavior in this study also appears to be influenced by the status of PPFPE (e.g., safety nets). In the five cases involving PPFPE, the workers
themselves had all helped in some way to install the equipment and, therefore, were aware of its presence. However, the equipment played a direct role in only one of the five cases, whereas in the other four cases the workers either fell outside the perimeter of the safety net or had not attached their lifeline. PPFPE was more likely to be present when serious injuries occurred than when fatal injuries occurred. This is too small a sample to draw any statistical conclusions from, however, the sample size need only be two to three times greater if the odds ratio (OR=6) for the status of PPFPE were to be statistically significant at the 5% level.

The lack of PPFPE in 9 of the 10 fatal fall injuries appears to support the theory that lack of PPFPE contributes to heightened risk perceptions and safe behavior, at least in the morning hours. However, the increased mental and physical energy involved in increased safe behavior can provoke fatigue later on in the day, which is when the fatal injury incidents primarily occurred, resulting in reduced reactions and reflections. This can then result in behavioral errors, and reduced ability to prevent head injuries.

In contrast, the greater presence of PPFPE in serious fall incidents may contribute to explaining why a greater number than expected of seriously injured workers (8 of the 10) fell during the morning hours. PPFPE appears in these cases to have resulted in decreased risk perception and less safe behavior already early during the workday, which is when these incidents primarily occurred. However, unlike the fatally injured workers, the seriously injured workers were, at the time of their falls, not as affected by fatigue, and thus were more alert with quicker reflexes and, therefore, possibly better able to prevent hitting their heads against the cement floors.

The results in this study are somewhat reflective of those found by Salminen et al. (1992) in that work habits (i.e., risk taking in the current study) appear to have accounted for a greater proportion of nonfatal/serious injury incidents, whereas organizational factors (i.e., unavailability of PPFPE in the current study) and handling of materials appear to have played a greater role in fatal injury incidents. The results in this study on the use of PPFPE are also reflective of Wilde’s (2001) research and review of studies into the risk compensatory effects of passive protective equipment in road vehicles (e.g., seat belts and airbags). However, very little was found in the literature on PPFPE status in occupational injury incidents. The results regarding the disproportionate attention to PPFPE in this study points to an area for further focus.

Some recent studies have begun to report on the use of PPE in occupational injury incidents. However, these studies are often based solely on fatal injury incidents, which do not allow for direct comparisons to the results in this study. In Cattledge, Schneiderman, Stanevich, Hendrick, and Greenwood’s (1996) study of 182 nonfatal construction falls in West Virginia (Workers’ Compensation data), they found through telephone interviews with the victims that “hardly any” of them had used fall protection devices. Responses given for not using fall protection devices were that they were not needed, they were not supplied, they were too difficult to use while performing a job, the workers did not know what fall protection devices to use, or that the work environment could not adequately accommodate fall protection devices.

The third risk factor identified in this study that appears to differentiate whether a fall through a roof results in fatal or serious injuries is the farm versus nonfarm location of the workplace. A majority of the fatal construction injuries involving falls through roofs occurred on farm buildings, whereas the locations of the workplaces were more diversified
for serious injury falls. The rural isolation of farms can influence a number of risk factors. Employers and employees may feel less inclined to conform to workplace safety regulations when working at farms, as the chances of the authorities discovering the violations are relatively small, as opposed to working in a city. The rural isolation of farms can also mean that a fall though a farm roof may go undetected for a relatively and crucially longer period of time, and professional medical attention may be initiated relatively longer after a fall at a farm than in a city. A possible solution to this problem could be that construction workers be equipped with cell phones with a preprogrammed number for local emergency medical services, in order to reduce the time between injury and medical treatment. In general, the results in this section point to a need for further research into the status of PPE for work done on farms in comparison to other locations. In addition, the high geographic concentration of the fatal and serious injury incidents in rural counties points to areas for increased fall prevention measures.

The utility of investigation reports from the Working Environment Authority and police reports in this study was somewhat limited, in that serious injury incidents are investigated to a much lesser degree, and investigations are primarily focused on establishing which regulations have been violated and by whom. There is, therefore, a need for studies using an in-depth approach to analyzing injury incidents that not only look at the interaction of immediate risk factors surrounding the injury incidents such as technical, human, and environmental factors, but also look at underlying risk factors such as social, cultural, and organizational factors. For example, Spangenberg et al. (in press) found that a higher education and training background was a likely contributing factor to a higher level of safety in the Swedish construction industry, compared to the Danish construction industry.

The results regarding the time of day of the fall injury incidents in this study is a good example of how the credibility of research findings using a small sample can be tested against a larger existing data set. In this case, comparisons of the time of day of the incidents were made using national data sets from both Denmark and Sweden. However, personal fall protective equipment status is much more difficult to test on a larger data set, as recording of the use of PPE is not yet standardized in the reporting system. There is, therefore, a need for including PPE status in the reporting of injury incidents, such as the categories used by Bradee, Hause, and Pratt (2000), including a short text description of the effectiveness of the equipment. This step will probably be as relevant for other types of injury incidents as it is for falls from heights.

5. Conclusions

The results in this study point to at least three risk factors in the surrounding circumstances of construction workers’ elevation falls through roofs that differentiate between fatal and serious injury incidents. Fatal fall injury incidents occurred predominantly on farm buildings and in the afternoon hours. Fatigue was a likely contributing factor both in terms of initiating the fall, as well as in the workers’ reduced ability (reactions/reflexes) to prevent fatal head injuries. This fatigue may have been intensified by the increased mental and physical energy required for increased risk perception and safe
behavior throughout the working day, as the fatally injured workers, to a much lesser degree, used passive personal fall protection equipment.

In contrast, seriously injured worker falls involved a wider variety of buildings. They disproportionately fell in the morning hours, where fatigue was much less prevalent, and therefore the workers were better able (reactions/reflexes) to prevent fatal head injuries. The seriously injured workers’ greater use of PPFPE was a likely contributing factor for the disproportionate number of falls in the morning hours, as it may have resulted in decreased risk perception and less safe behavior.

In addition to safety education, training, and enforcement, lightweight bicycle-type (strap-on) helmets may contribute to preventing fatal injuries. Construction workers, especially those working in relatively isolated locations (e.g., farms) could be equipped with cell phones with preprogrammed telephone numbers to local medical services, in order to reduce the time between injury and medical treatment.

Future research should examine the status of PPE in both fatal and nonfatal injury incidents in a larger sample and for other types of injuries incidents. In addition, occupational injury surveillance systems should begin, systematically, to collect data regarding the status and role of PPE in injury incidents.

6. Impact on industry

The impact on industry of this study is the identification of a need for systematic recording of personal protective equipment (PPE) status in injury surveillance systems, which will allow for more quantitative and qualitative evaluations of the role of (PPE) in injury incidents, in particular, the status and use of PPE on farms.

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