Pergamon

Accid. Anal. and Prev., Vol. 28, No. 5, pp. 627–636, 1996

0001-4575/96 $15.00 + 0.00

S0001-4575(96)00035-8

THE IMPACT OF MAJOR TRANSFORMATIONS OF A PRODUCTION PROCESS ON AGE-RELATED ACCIDENT RISKS: A STUDY OF AN IRON-ORE MINE

VERA L. G. BLANK[1,2], LUCIE LAFLAMME[2,3]* and FINN DIDERICHSEN[2]

[1]Federal University of Santa Catarina, Health Science Centre, Department of Public Health, CEP 88.010-970 Florianópolis/SC, Brazil; [2]Karolinska Institute, Department of Public Health Sciences, Division of Social Medicine, S-172 83 Sundbyberg, Sweden; [3]National Institute of Public Health, Injury Prevention Programme, P.O. Box 27848, S-115 93 Stockholm, Sweden

(Received 12 September 1995; accepted 20 February 1996)

Abstract—This paper describes a study of whether accident risks were equally distributed across age categories among a population of mining workers whose work activities were suspected to be age-impaired. The impairment factors in focus are the transformation of production technology during the 80s and consequent changes in job content. It was hypothesized that the combined effect of these factors might lead accident risks, both non-specific (aggregated) and specific (by kind), to increase with age. Accident risk ratios (ARRs), however, proved to be higher for younger workers than older ones, in both the non-specific and the specific cases. However, two accident patterns (specific risks) also show relatively high ARRs among workers in their 40s (and even 30s), results that might be explained by particular exposures and/or age-related performance problems. The findings suggest that technological changes designed to increase productivity and reduce staffing levels more rapidly affect efficiency and productivity than they do accident occurrence, and that they penalize young workers in the first instance. Copyright © 1996 Elsevier Science Ltd

Keywords—Aging, Technological development, Accident pattern, Poisson regression, Mining industry

INTRODUCTION

Individual ability to cope with occupational demands is often presumed to diminish with age as a result of the progressive weakening of physical and mental capacities. In many instances, however, older workers have the capacity to reduce difficulties in meeting job demands through acquired experience and the more efficient utilization of their personal resources (Laville 1989; Teiger 1989; Volkoff 1989; Salthouse 1990; Davies et al. 1991; Gary 1991; Ilmarinen 1991; WHO 1993). In fact, as posited by Warr (1993, 1994), for performance to be 'age-impaired', work activities must have two characteristics: that individual capacities are exceeded by job demands to a greater extent in the case of older workers and that experience is unable to compensate for age-related shortcomings.† Examples of activities of this kind are continuous rapid information processing and some types of strenuous physical activity. Such activities may involve rapid learning or be subject to rapid change.

The consequences of age-impairment factors on individual performance and well-being need to be thoroughly researched, especially at a time when the reasonableness of the set of demands currently imposed on workers is being put into question as a result of the aging of the working population (WHO 1993). One possible negative consequence that deserves special attention is that work safety becomes less assured as age increases, resulting in a higher frequency of accidents among older workers (WHO 1993; Laflamme and Menckel 1995).

At first sight, however, the literature on work-related accidents provides scant support for the view that age and accidents are positively related (Dillingham 1981; Landen and Hendricks 1992); on the contrary, it points to the likelihood of possession

*Address correspondence to Dr Lucie Laflamme, Karolinska Institute, Department of Public Health Sciences, Unit of Social Medicine, S-172 83 Sundbyberg, Sweden.

†Warr suggests that understanding age-related performance at work would benefit greatly from regarding performance in the light of three sets of attributes: physical abilities, adaptability, and general work effectiveness. While both physical abilities and adaptability tend to decline as people grow older (with wide individual variation), general work effectiveness might remain stable or even increase with age. He has proposed a framework within which occupational activities are divided into four categories: 1. age-impaired, 2. age-counteracted, 3. age-neutral, and 4. age-enhanced.

of compensatory ability on the part of older workers (for a review, see Laflamme and Menckel 1995). Unfortunately, this evidence rests largely on large-scale and cross-sectional studies, which restricts the conclusions that can be drawn, especially when age-impaired activities are in focus. In addition, in several accident studies, statistical techniques requiring a normally-distributed dependent variable have been employed while, in fact, the expected distribution for occupational accidents is a Poisson one. Despite this, it is worth noting that some research findings suggest that age-related accident risk may be specific rather than diffuse, in the sense that older workers may be at greater risk with regard to certain types of accidents, such as those incurred to the back and lower limbs (Root 1981; Oleske et al. 1989; Cloutier 1994).

Against this background, the current study was embarked upon in order to analyze age-related accident risks, both non-specific (aggregated) and specific (by kind), in a population of mining workers whose age structure was aging rapidly. Some occupational activities in the mine were suspected to be age-impaired, in general because of the heavy physical demands they imposed, and in particular because of the more or less continuous change in job content that had taken place over the previous decade. The latter was the joint effect of two factors: the progressive transformation of (already-advanced) production technology, and accompanying cutbacks in personnel.

While transformation of production technology in the 80s contributed to making work in the mine less hazardous (Eriksson 1991), and led to a reduction of accidents in the mine over that decade, the question of whether the reduction applied to the same extent to all transformation phases, to all age categories of workers and to all kinds (patterns) of accidents remained unanswered.

MATERIALS AND METHODS

The study group and the mine

The study group consisted of miners working at the underground-extraction phase in a Swedish iron-ore mine between 1980 and 1993. This period was characterized, in the first instance, by important changes in the age structure of the working population. From comparing the age distributions of underground workers in this mine with those of all male iron-ore miners and male manufacturing workers during three time periods (see Table 1), it can be seen that the pace of aging of the population of underground mine workers under study was much more rapid than those of the other occupational groups. This is most evident for the age categories 40–49 and 50–59.

As mentioned above, the study period was characterized by the making of constant improvements to already-advanced production technology, especially at the extraction phase. Activities at this phase included drilling, charging and rock blasting, scaling, supporting of rock, loading, chute-loading and the transportation of rock. As early as the beginning of the 1980s this phase was highly mechanized, and most of the changes implemented during the period (such as the introduction of a new mining system, automatization of some operations and the acquisition of new equipment) were designed to increase productivity and the efficiency of the mining process (Eriksson 1991).

Among the major implications of all this for the workforce were, drastic cutbacks in personnel and steady reductions in the need to make and the scope of direct interventions. Further, most tasks were either transformed through the introduction of new equipment or wholly replaced by new assignments. Physical demands were reduced in some instances but not totally eliminated (Eriksson 1991).

Data preparation

For the purpose of the study, accident data (our numerator data) were taken from all the 359 accident declarations describing accidents occurring during ore-extraction in the mine between 1980 and 1993 (excluding accidents traveling to and from work) that had reached Sweden's Information System on Occupational Injuries (the ISA-system). The ISA is based at the Swedish National Board of Occupational Safety and Health and contains information on all occupational accidents, reported to the public insurance authorities, resulting in at least one day of absence from work (NBOSH 1992). The ISA data allowed all accidents to be categorized by year of occurrence and age of injured worker.

The number of workers exposed at the extraction phase was estimated on the basis of data obtained from the company on the total number of workers involved in underground activities (see the final column of Table 2); information on the number of workers by year of birth for each year covered by the study was also supplied by the company. No information, however, was available on the number or ages of workers involved directly in ore-extraction. It is not the practice of the company to compile individual information from any of its work sites. For the study period, however, the company estimated that extraction work took up an average of 45% of the working hours of all underground personnel. The assumption was made that the total number of underground

Table 1. Age distribution (%) of underground workers at the mine under study (U-G), of male iron-ore miners in general (I-O) and male manufacturing workers (M) for three time periods

	1980			1985			1990		
Age	U-G	I-O	M	U-G	I-O	M	U-G	I-O	M
<30	22.3	28.1	27.6	4.2	14.8	28.9	14.3	20.8	29.2
30–39	30.0	25.8	25.5	30.8	30.5	24.2	23.5	23.5	22.3
40–49	27.7	24.6	19.3	31.1	28.8	22.5	32.7	32.1	24.2
50–59	20.0	20.4	19.2	33.9	25.3	17.2	29.5	23.4	17.2
60+	0.0	1.1	8.5	0.0	0.4	7.3	0.0	0.1	6.8
n	1718	2225	707,240	1020	1562	668,168	898	1259	651,129

Table 2. Annual data on the extraction phase at the mine and total number of personnel working underground during the study period

Year	Production volume (in 1000 tons)	Hours worked	Production volume by hour worked (in tons)	Number of accidents ($n=359$)	Number of workers (underground)*
1980	19,200	921,900	20.83	72	1718
1981	16,100	890,200	18.09	64	1770
1982	11,000	561,400	19.59	32	1307
1983	8,300	530,700	15.64	35	1200
1984	12,200	361,400	33.76	20	1077
1985	16,100	395,500	40.70	15	1020
1986	17,800	387,400	45.94	13	911
1987	15,600	349,900	44.60	19	959
1988	16,700	367,400	44.50	22	788
1989	18,700	395,200	47.30	20	896
1990	17,700	422,400	41.90	13	898
1991	17,700	426,700	41.50	15	917
1992	18,000	373,700	48.20	14	991
1993	18,300	395,900	46.20	5	957

*Values used as estimates for denominators in the calculation of the annual accident rates employed in the Poisson regression.

workers and also their distribution by age category could be used to construct denominators for the extraction phase. This gives rise to an overestimation of the number of workers exposed, both overall and by age category, and consequently to an underestimation of accident risks. Nevertheless, as these data have not been used to calculate incidences by age category but only to compute risk ratios, the consequences of this overestimation are not severe in relation to the specific purpose of this study.

Statistical analysis

Non-specific accident risks (all accidents aggregated) and specific risks (by accident class) were analyzed as follows.

The full study period was divided into three subperiods, based on average annual production volume per worked hour at the extraction phase (see Table 2), a measure that was used to estimate productivity and its development over time. The three time periods differed in certain key respects and can be denoted as follows: 1. fall in productivity and hours worked (1980–83); 2. rise in productivity and stabilization of hours worked (1984–89); and 3. fairly stable balance between productivity and hours worked (1990–93).

The study population was divided into four age categories: <30, 30–39, 40–49 and $\geqslant 50$ years-old. The age category <30 mainly comprises workers in their 20s, and the age category $\geqslant 50$ mainly workers in their 50s. In fact, only during the years 1992 and 1993 did the latter category contain any workers older than 60.

Accident rate ratios (ARRs) and 95% confidence intervals (95% CIs) were calculated using the Poisson-regression method (Kleinbaum et al. 1988). The time period 1990–93 and the age category $\geqslant 50$ were used to provide reference values, on the grounds that they displayed the lowest accident risk. The regression models (one each for non-specific and specific accidents) were first fitted with number of accidents as the dependent variable, and time period and age category as independent variables. The model was then extended to include the interaction term ‘time period and age category’, and tests for interaction effects were conducted. The likelihood ratio statistics

(LRSs) of the extended model were used to determine whether the interaction term should be included in the regression models (see Kleinbaum et al. 1988), a p-value equal to or less than 0.05 being the criterion for inclusion. The number of exposed workers underground was used as the rate multiplier. The regression models were fitted using the statistical package EGRET (Statistics and Epidemiology Research Corporation and Cytel Software Corporation 1985).

In order to identify specific accident patterns (specific risks), two multivariate statistical methods were used in sequence: the Factorial Analysis of Correspondence (FAC) and the Hierarchical Ascendant Classification (HAC) (Fénelon 1981; Greenacre 1984; Benzécri 1985). These methods were adopted since the accident declaration forms filled out by the company contained such good quality information that they enabled the coding of a number of variables either not included at all in the Swedish official statistics or coded there with less precision. The nature of the results that these methods generate ('accident scenarios', see Laflamme et al. 1993) and the support they potentially offer for preventive work in the workplace provided further grounds for following this procedure.

Hence, in addition to the already coded information provided by the ISA, the research team went through all the individual accident-declaration forms, coding four variables for use as accident descriptors: the site where the accident occurred, the type of task performed by the injured worker, the broad category of machinery, equipment or object involved (if any), and (where information was available) the specific machine, tool or object concerned.*

In the FAC and HAC analysis, five variables were treated as active†: main event, causal agent, specific machine, tool or object concerned, part of the body injured and type of injury; and three variables were treated as illustrative‡: site of occurrence, task involved, and broad category of machinery, equipment or object involved.¶

It should be noted that the HAC maximizes the variance (inertia) between classes and minimizes that between classes. The inter-class inertia is a measure of the separateness of classes (i.e. how distinct they are from one another (see Fénelon 1981; Benzécri 1985). The higher the inter-class inertia, the greater is the difference between classes. The intra-class inertia is the measure of the internal consistency of a class (i.e. its compactness, or the degree of similarity between the events forming the class). The lower the intra-class inertia, the greater is internal class consistency. The sum of the inter-class and intra-class inertias is equal to 1 (i.e. 100%). The FAC and HAC, as they can be applied in the arena of occupational accidents, are more extensively described in Laflamme et al. (1991,1993).

RESULTS

Non-specific accident rate ratios

Table 3 presents the accident rate ratios (ARRs) with 95% confidence intervals (in brackets) by time period and age category for all accidents aggregated (second column), and also for each accident class separately (third to seventh columns).|| The ARRs for each accident class will be commented upon below after these classes (patterns) have been described.

The ARRs for all accidents aggregated are derived from the Poisson regression model including the interaction term 'age and year'. That inclusion of the interaction term significantly improved the fit of the model (LRS $p = 0.02$) means that the period and age variables had a combined as well as an independent effect on accident rates.

Table 3 shows that, all accidents aggregated, ARRs differed greatly over time and between age categories. The rates were more than two and a half times higher in the first and second time periods (1980–83; 1984–89) than in the reference period (1990–93). Rates were also above three times and two and a half times higher for the two younger age categories, <30 years and 30–39 years-old respectively, than the older age group (50 and over). Only

*The variable 'specific machine tool or object concerned' is a descriptive variable used to complement 'broad category of machinery, equipment or object involved'. The former refers to the task performed by the worker when the injury was incurred, the latter to the physical object involved in the course of the injury event.

†The active variables, by contrast with the illustrative, are the ones that contribute to the calculation of the variance and to the formation of the factorial axes (see examples in Laflamme et al. 1991, 1993). The variables here chosen as active define characteristics of the injuries.

‡The illustrative variables are not included in the calculation of the variance and do not contribute to the formation of the factorial axes. Their contribution can be estimated only after the axes have been formed (see examples in Laflamme et al. 1991, 1993). They are used to search for contextual explanations for any one of the injury patterns.

¶'Specific machine tool or object concerned' and 'broad category of machinery, equipment or object involved' were not given the same status in the analysis because of the redundancy in some of the information they procure. Using the two as active would have had the unfortunate (and undesirable) effect of multiplying by two the weight of this type of information compared to that of the other variables. 'Specific machine tool or object concerned' has been treated as active since there was already one variable describing the causal agent of the injury treated as active.

||ARRs differ significantly from their reference category when the lower 95% CI is equal to or greater than 1.00.

Table 3. ARRs with 95% confidence intervals by time period and age category, all accidents aggregated (non-specific) and by accident class (specific)

Variable		All accidents* $n=359$	Class 1† $n=100$	Class 2‡ $n=71$	Class 3‡ $n=72$	Class 4‡ $n=66$	Class 5‡ $n=50$
Period							
	1980–83	2.54	2.39	2.79	2.75	2.57	2.11
		(1.08–5.97)	(1.36–4.22)	(1.30–5.98)	(1.40–6.65)	(1.20–5.53)	(0.91–4.87)
	1984–89	2.63	1.84	3.21	2.63	2.86	2.51
		(1.10–6.29)	(0.97–3.49)	(1.44–7.15)	(1.19–5.82)	(1.26–6.51)	(1.03–6.09)
	1990–93	1.00	1.00	1.00	1.00	1.00	1.00
Age							
	<30	3.22	2.06	3.60	7.30	7.74	4.56
		(1.25–8.31)	(1.13–3.75)	(1.50–8.65)	(3.14–16.97)	(2.86–20.92)	(1.57–13.26)
	30–39	2.77	1.12	3.52	2.36	4.40	3.39
		(1.12–6.86)	(0.63–1.98)	(1.13–5.65)	(0.99–5.63)	(1.68–11.51)	(1.26–9.10)
	40-49	2.01	1.14	2.68	2.35	2.81	2.49
		(0.82–4.93)	(0.65–1.99)	(1.21–5.93)	(0.99–5.56)	(1.04–7.61)	(0.90–6.85)
	≥ 50	1.00	1.00	1.00	1.00	1.00	1.00

*Based on regression model with interaction term 'year and age'; LRS $df=6$, $p=0.02$.
†Based on regression model without interaction term 'year and age'; LRS $df=6$, $p=0.10$.
‡Based on regression model without interaction term. No LRS possible due to lack of convergence.

the ARR of the group of 40–49 year-olds did not differ significantly from the reference value.

Specific accident rate ratios

Description of the accident classes. The FAC and the HAC brought to light five particular accident classes (patterns). These were obtained once an HAC had been performed on the first two factors of the FAC (accounting for a cumulative 15.9% of the total inertia). The distribution of the accidents within each class, one variable at a time, is shown in Table 4 (active variables in the FAC) and Table 5 (illustrative variables). A title for and brief description of each class (pattern) are provided below.

Class 1. Upper-body contusions due to projected or falling objects (11.9% inertia; 100 accidents). Class 1 groups contusions and crushing injuries, to the head, face and chest, resulting from contact with a projected or a falling object (e.g. a stone, or some material or product). The injuries were sustained most typically while the worker was using a hand-held (or undefined) tool (e.g. a scaling rod). They occurred more often than expected on scaling sites and during the performance of direct production tasks.

Class 2. Upper-limb injuries while handling machines or tools (9.0% inertia; 71 accidents). Class 2 primarily encompasses handling injuries resulting, in many instances, from contact with handled machines or tools (e.g. drilling machines). Such contact gave rise to cuts, and also to contusions and crushing injuries, to the arms, hands or fingers. The injuries were most typically incurred on drilling sites, and more often than expected when workers were correcting a mechanical malfunction.

Class 3. Falls and contacts with moving objects (13.4% inertia; 72 cases). The injuries included in class 3 are mainly skeletal, and were sustained either due to contact with a moving object or as a result of a fall. A loading machine was quite often involved, and, in a few other cases, a lifting device or truck. These accidents occurred more often than expected when a worker was moving on or around a machine (e.g. getting out of it), and most typically took place on loading sites.

Class 4. Sprains and strains to the lower limbs due to stumbling or falling (12.9% inertia; 66 accidents). Injuries in class 4 comprise sprain and strain injuries to the lower limbs sustained either on or around machines (e.g. a charging device or high-power drilling unit) or on structural parts. They were sustained more often than expected when workers were moving from one place to another in their working area, and on drilling and charge-and-rock-blasting sites.

Class 5. Overexertion injuries to the back, neck or shoulders (5.36% inertia; 50 accidents). Class 5 encompasses sprain and strain injuries to the back, neck or shoulders caused by an overexertion while the worker was manipulating some material, product or work piece. It was rare for a tool to be used when such accidents occurred, but it was quite frequent for the worker to be involved in the task of servicing machinery.

ARRs by accident class. The ARRs presented above in Table 3 for class 1 (upper-body contusions) are based on the initial Poisson regression model not including the interaction term 'age and year' (LRS $p=0.10$). This was because separate period and age effects, but no combined effect, on the accident rate was detected in the case of this kind of injury. ARRs

Table 4. Characteristics of the five accident classes (patterns) — active variables in the FAC

Variable		Class 1 $n=100$	Class 2 $n=71$	Class 3 $n=72$	Class 4 $n=66$	Class 5 $n=50$	Total $n=359$
Main event	Falling	21	—	*25*	18	1	65
	Stumbling	4	2	7	*33*	—	46
	Contact with object						
	* flying or falling	*58*	13	1	3	—	75
	* moving	—	7	*31*	1	—	39
	Overexertion	—	—	1	9	*47*	57
	Handling injury	3	*47*	7	2	—	59
	Other main event	*14*	2	—	—	2	18
Causal agent	Hand-held machine	7	40	1	—	3	51
	Lift, transport device	2	1	61	6	—	70
	Work-related machine, not hand-held	1	13	—	*28*	1	43
	Other machine	13	6	1	7	7	34
	Structural part	*46*	3	2	*23*	4	78
	Material, product	*23*	7	4	2	*16*	52
	Other agent	5	1	2	—	*19*	27
	Personnel equipment	3	—	1	—	—	4
Specific, machine, tool or object concerned	High-power drill unit	6	19	1	*26*	8	60
	Loading machine	4	—	*42*	3	3	52
	Scaling rod	*24*	8	2	—	5	39
	Hand-held drilling machine	11	*15*	3	4	4	37
	Charging device	7	1	5	*20*	1	34
	Lift, truck, platform	13	1	*14*	4	4	36
	Other tool	4	18	2	—	5	29
	Inapplicable	13	1	3	7	*12*	36
	Unspecified	*18*	8	—	2	8	36
Part of body	Face, head, eyes	*40*	17	17	6	3	83
	Neck, shoulders	4	—	5	3	*27*	39
	Back	12	3	14	8	*15*	52
	Hand, wrist, finger/left	13	*29*	11	4	1	58
	Hand, wrist, finger/right	9	*18*	7	3	—	37
	Hip, leg, foot/left	11	2	7	*14*	2	36
	Hip, leg, foot /right	7	2	11	*27*	2	49
	Several body parts	4	—	—	1	—	5
Type of injury	Sprain, strain	4	—	20	*45*	*50*	119
	Wound	25	*34*	8	1	—	68
	Contusion, crushing	*51*	*29*	21	18	—	119
	Skeletal injury	14	8	*20*	2	—	44
	Other injury type	6	—	3	—	—	9

The values marked in italics are those of the categories that contributed significantly to the formation of the classes within each variable; i.e. there were a greater number of accidents than expected in these categories, $p<0.05$.

for this accident class were significantly greater than those of one of the reference categories in only two instances: for the first time period (1980–83) compared with the final period (1990–93), and for younger workers (<30 years-old) compared with older ones ($\geqslant 50$).

For the other accident classes (2–5) it was not possible to test for the significance of including the interaction term in either of the regression models. There was a lack of convergence and no LRSs were calculable.

Table 3 shows that the ARR profiles of class 2 (upper-limb injuries while handling machines or tools) and class 4 (sprains and strains to the lower limbs due to stumbling or falling) were very similar. In both cases, the ARRs for the two time periods preceding the reference period were significantly higher (two and a half times or more) than that of the latter. Moreover, the ARRs of all age categories were significantly higher than that of the reference category (older workers).

ARRs in class 3 (falls and contacts with moving objects) were also significantly higher in the two time periods preceding the reference period, but workers younger than 30 years of age comprised the only group whose ARR was significantly (and substantially) higher than that of the reference group comprising older workers.

Finally, looking at time-related ARRs in class 5 (overexertion injuries to the back, neck or shoulders), it can be observed that, by contrast with all other classes, the first time period did not show a significantly higher ARR than the reference period. It was only to the middle time period that such a difference

Table 5. Characteristics of the five accident classes (patterns) — passive variables in the FAC

Variable		Class 1 $n=100$	Class 2 $n=71$	Class 3 $n=72$	Class 4 $n=66$	Class 5 $n=50$	Total $n=359$
Site of occurrence	Drilling	22	41	4	35	20	122
	Charge, rock blasting	19	9	8	*24*	13	73
	Scaling	*33*	8	9	1	7	58
	Loading, chute loading, transport of rock	16	3	*47*	5	6	77
	Others*	10	10	4	1	4	29
Task involved	Production tasks	*73*	40	36	26	26	201
	Servicing machine	10	14	9	10	*15*	58
	Correction of malfunction	4	*16*	5	2	2	29
	Moving on or around a machine	13	1	*22*	*28*	7	71
Category of machinery, equipment or object involved	Hand-held machine or tool	*37*	*36*	5	3	10	91
	Lift or truck	20	5	*56*	24	8	113
	Other machine (stationary or mobile)	9	19	5	*27*	10	70
	Other technical device	6	4	3	3	4	20
	Unspecified	*17*	6	—	2	8	33
	Inapplicable	11	1	3	7	*10*	32

*Others: e.g. supporting of rock, tube dragging, manual loading.
The values marked in italics are those of the categories that contributed significantly to the formation of the classes within each variable; i.e. there were a greater number of accidents than expected in these categories, $p < 0.05$.

applied. The age-related ARRs of the two younger age categories but not that of the group aged 40–49 were significantly higher than that of the reference group comprising older workers.

DISCUSSION

The study consisted of an investigation into whether non-specific and specific accident risks were equally distributed across time and age categories in a rapidly aging mining working population whose work activities were suspected to be 'age-impaired' (Warr 1993, 1994).

Limitations of the study

Number of exposed workers by age category. A first limitation of the study lies in the lack of precise data on the number of exposed workers involved at the extraction phase, both in total and by age category. For the purpose of the analysis presented here, the assumption was made that the age distribution that prevailed among all underground workers was the same as that for workers involved specifically in ore-extraction. If this assumption is correct all individual age-related ratios (but not ARRs) will be underestimated, since workers employed at the extraction phase comprise only a fraction of the underground work force (working approximately 45% of the total number of hours worked underground each year). Nevertheless, as these data have not been used to calculate incidences by age category but only to compute risk ratios, the consequence of this underestimation is not severe in relation to the specific purpose of this study.

In the case, however, that the assumption is incorrect, and that the number of older workers exposed (the workers in the reference category) was overestimated, actual ARRs would be smaller than those currently obtained. But, since the extraction phase can be regarded as the mine's 'front line', requiring skill and experience on the part of the work force, it is more likely that the proportion of older workers (50 and over) employed in extraction may be somewhat underestimated. This would mean that the ARRs for the younger groups are underestimates.

The interaction term 'year and age'. A second limitation of the study results from the impossibility of testing for the contribution made by the interaction term 'year and age' in the case of four accident classes out of five. Without disrupting the qualitative differences observed in ARRs, this limitation has two disadvantages. The first is that it reduces the reliability of the figures obtained. The second is that it leaves an important question unanswered, namely "Do time and age jointly (as well as independently) contribute to the distribution of accident risks?"

It was observed, for instance, that, all accidents aggregated, the interaction term did make a significant additional contribution to the explicative value of the model. And this can be regarded as evidence that, during the study period, time (as a measure, here, of three phases of technological development) and age, jointly and not just independently, affected accident-risk distribution. In other words, non-specific ARRs did not follow the same trend for all age groups (most likely, rising in the case of younger workers and falling in the case of others).

For its part, the absence of significant interaction for class 1 (the only interaction effect that it was possible to test) suggests that technological changes and age contributed independently but not jointly to accident-risk distribution. These accidents had a tendency to decline in frequency over the years (probably in all age groups); but, when they did occur, they primarily tended to affect younger miners.

Absence of clear information on job content. A third limitation of the study lies in lack of information on (and measures of) the workload to which ore-extraction workers were exposed. No data on differences between age categories and the way in which the pace or rhythm of work changed over the years were considered. Analysis of such data was beyond the scope of the current study, but it would be interesting to pay attention to the issues such analysis might raise in future studies.

The 'healthy-worker effect'. One final possible bias in the data lies in the possibility that the older persons who remained in the workforce after the age of 50 (the reference category) constituted a 'select' group of not only healthier but also more skilled workers than those who had left the mine during the study period. If this was the case, the older workers remaining in the mine might have been less accident prone than would have been expected simply on grounds of their competence and health. The extent to which this factor 'under represents' the accident risk faced by older workers in general is not possible to measure, and how much it has affected the results of the study remains unclear. Despite this, workers younger than 30 seem to be the great 'losers' among the study population in terms of accident susceptibility.

Time-related ARRs

The time-related ARRs computed for all accidents aggregated and for the accident classes separately showed roughly comparable patterns. Interestingly, in almost all cases, not only the first but also the second time period showed a significantly higher ARR than the final (reference) period. This is an indicator that major transformations in production technology and working methods require time before they effect significant changes in accident occurrence. Their impact on efficiency, productivity and profitability, and even on occupational hazards, however, is more rapid (Eriksson 1991). In addition, as will be discussed later, some age categories may benefit more from such technological developments than others.

The two exceptions to this general trend (of ARRs being higher in the two first period than in the last) are for accident-class 1, where only the ARR of the first time period was significantly higher than the reference value, and for class 5, where only the ARR of the second time period was higher. The absence of a significant difference for the second time period in the case of class 1, a class in which a large number of injuries were incurred on scaling sites, might be explained by the introduction into the mine (for the first time) of a mechanized scaling machine (used after blasting, see Eriksson 1991) at the beginning of this period (1984). In the case of class 5, it can be hypothesized that the work tasks most typical of this class, in particular those concerned with the servicing of machinery, were not clearly enough organized or defined, or might have had to be performed more often during the second time period.

Age-related ARRs

When considering age-related ARRs for all accidents aggregated, the results suggest that the changes being implemented in the mine favoured rather than penalized older workers, i.e. those in their 50s (and over), and also, it seems, ones in their 40s. Indeed, when compared with the ARR of older workers (50 years and over), ARRs for the groups younger than 30 years-old, and 30–39 emerge as significantly higher; by contrast, the ARR for workers in their 40s (40–49) is not significantly different. Even when looking at ARRs one class at a time, younger workers (under 30) systematically recorded higher ARRs than members of the oldest group. The profiles of the intermediate age categories (30–39 and 40–49), however, varied with accident class.

Higher ARRs among younger workers. In a sense, finding higher ARRs among younger workers is not a new finding. The phenomenon has been observed in several studies concerned with the relation between age and occupational accidents (Laflamme and Menckel 1995). What is peculiar to the current finding is that it applies to a working population for which there are good reasons to believe that the performance capacity of older workers and, as a consequence, their work safety, were under threat. The nature of this threat lay in the continuous changes made to job content.

This lack of evidence for major changes in job content having a greater impact on older workers might have at least two, not mutually exclusive, explanations. The first is that risk exposure between age categories is unequal, which might favour older workers even if all age groups, including the older group, are subject to changes in work content. The work performance of older workers might have been affected, but without this having significant repercussions on their accident rate. Further, the greater the apparent exposure to risk of workers in the younger age category might be the product of two factors: a physical and technical work environment that is genuinely more hazardous, or a lack of relevant experience when confronted by new and unfamiliar assignments (Warr 1993, 1994).

The second explanation is that only (or almost exclusively) workers from younger age groups were exposed to substantial changes and higher accident risks during the study period. Noteworthy in this respect are the results for classes 1 (upper-body contusions) and 3 (falls and contacts with moving objects), where only younger workers had significantly higher ARRs than older ones. These classes happen to be the ones where injuries were typically incurred in the handling of machines or tools, or moving on or around machines and vehicles during production.

It is also possible, however, that the recruitment of workers younger than 30 which took place between 1985 and 1990 (see Table 1) was not accompanied by sufficient training with regard to the specific nature of the job tasks to be performed. This hypothesis is supported by the fact that, all accidents aggregated, the ARR of younger workers (<30 years) doubled between the first and the second time period. This major increase, which did not apply to other age groups, is further illustrated by the time-related ARRs by age group presented in the Appendix.

Some specific risks even for workers in their 40s. There are two accident classes where the age-related ARRs support the idea that, in particular circumstances, workers in their 40s (and even 30s) might be at greater risk of incurring an injury than workers who have passed 50. These two classes are class 2 (upper-limb injuries while handling machines or tools) and class 4 (sprains and strains to the lower limbs due to stumbling or falling). For these classes, workers in the 30–39 and 40–49 groups registered ARRs significantly higher than that of the reference category, just as did younger workers.

The accident circumstances and injury types of class 4 have been shown to be associated also with higher accident frequencies among older workers in earlier studies (Root 1981; Oleske et al. 1989; Cloutier 1994), but not those of class 2. In the latter case, however, given the situation prevailing in the mine, it is not implausible to believe that the circumstances under which the accidents occurred posed particular performance problems for older workers (Warr 1993, 1994). The tools referred to in class 2 were certainly heavy, and were possibly also used in unfamiliar circumstances (e.g. when being in the vicinity of machinery). Alternatively, work procedures and equipment may have become too complex or been changed too rapidly for workers to be at ease in certain situations, e.g. when correcting certain malfunctions.

In fact, both performance impairment and higher exposure to risk or job demands may explain the 'surplus risk' of injuries in classes 2 and 4 faced by middle-age and older workers. Indeed, it is possible that there was a concentration of workers in their 30s and 40s on the sites where the accidents in these classes occurred most typically (i.e. drilling and charge-and-rock blasting sites). But, as stressed above, it is also quite possible that these workers were faced with job tasks in which performance might be affected by increasing age and where, in the case of the changes being made in the mine, experience was of no significant help (Warr 1993, 1994).

In this respect, interestingly, a closer examination of the ARRs by time period for each age category taken separately (results not presented here) reveals that it was just for these classes (2 and 4) that workers in their 40s (and only workers in this age range) showed an increase in their ARRs between the first and the second time period.

CONCLUSION

The hypothesis considered in the current paper is that the progressive transformation of production technology, parallel cutbacks in personnel and consequent changes in job content are age-impairment factors that increase the accident risks faced by older workers. The results obtained suggest that it is young workers (under 30 years of age) who are penalized by technological developments that lead to increased productivity and reduced staffing levels. Two accident patterns (specific risks), however, also show relatively high ARRs among workers in their 40s (and even 30s), results that might be explained by particular exposures and/or age-related performance problems.

Given the rapid aging of its work force and the substantial demands that the occupation imposes on the individual, further attention needs to be paid to any age-impairment problems that result from changes in job design at the mine. This is important for the future, and general lessons on the relationship between age and occupational accidents may be learned. Immediately, however, the need for technological change to be accompanied by adequate training is self-evident.

Acknowledgements—At the time of this study, the first author, Vera L. G. Blank, was financially supported by grants from CAPES (Post-Graduate Educational Federal Agency/Brazil). The authors would like to express their gratitude to Dr Ragnar Andersson and the statisticians Jette Möller, Peeter Fredlund and Michael Lundberg for their contributions to this paper.

REFERENCES

Benzécri, J. P. Introduction à la classification ascendante hiérarchique d'après un exemple de données économiques. Cahiers de l'Analyse des Données X(3): 279–302; 1985.

Cloutier E. The effect of age on safety and work practices among domestic trash collectors in Québec. Safety Science 17: 291–308; 1994.

Davies, D. R.; Matthews, G.; Wong, C. S. K. Ageing and work. In: Cooper, C. L.; Robertson, I. T. (eds) International review of industrial and organizational psychology, University of Manchester: Institute of Science and Technology. New York: John Wiley: 149–211; 1991.

Dillingham A. E. Age and workplace injuries. Aging and Work 4: 1–10; 1981.

Eriksson, U. Gruva och Arbete, Kiirunavaara 1890–1990. Doctoral thesis (part 4), Uppsala, University of Uppsala; 1991.

Fénelon, J. P. Qu'est-ce que l'analyse des données? Paris: Lefonen; 1981.

Gary A. Ergonomics of the older worker: an overview. Exp. Aging Res. 17 (3): 143–155; 1991.

Greenacre, M. J. Theory and Application of Correspondence Analysis. London: Academic Press Inc.; 1984.

Ilmarinen, J. Myths and facts about the development of the capacities of ageing individuals. Proc. Towards the 21st Century, Work in the 1990s, Int. Symp.Future Trends in the Changing Working Life, 13–15 August, 1991. Helsinki: Institute of Occupational Health: 226–236; 1991.

Kleinbaum, D. G.; Kupper, L. L.; Muller K. E. Applied regression analysis and other multivariable methods. Boston: PWS-KENT Publishing Company; 1988.

Laflamme L.; Döös M.; Backström T. Identifying accident patterns using the FAC and HAC: their application to accidents at the engine workshops of an automobile and truck factory.. Safety Sci. 14: 13–33; 1991.

Laflamme L.; Backström T.; Döös M. Typical accidents encountered by assembly workers: six scenarios for safety planning identified using multivariate methods.. Accid. Anal. Prev. 25: 399–410; 1993.

Laflamme L.; Menckel E. Aging and occupational accidents: a critical review of the literature of the past three decades. Safety Sci. 1: 145–161; 1995.

Landen D. D.; Hendricks S. A. Estimates from the National Health Interview Survey on occupational injury among older workers in the United States. Scand. J. Work Environ. Hlth 18 (2): 18–20; 1992.

Laville A. Vieillissement et travail. Le Travail Humain 52: 3–20; 1989.

NBOSH. Occupational diseases and occupational accidents 1990. Stockholm: National Board of Occupational Safety and Health; 1992.

Oleske D. M.; Brewer R. D.; Doan P.; Hahn J. An epidemiologic evaluation of the experience of a cohort of automotive parts workers: a model for surveillance in small industries. J. Occup. Accid. 10: 239–253; 1989.

Root N. Injuries at work are fewer among older workers . Monthly Labor Review March 30–34; 1981.

Salthouse T.A. Influence of experience on age differences in cognitive functioning. Human factors 32: 551–569; 1990.

Statistics and Epidemiology Research Corporation and Cytel Software Corporation. EGRET Reference Manual; 1985.

Teiger C. Le vieillissement différentiel dans et par le travail: un vieux problème dans un contexte récent. Le Travail Humain 52: 21–56; 1989.

Volkoff S. Le travail après 50 ans: quelques chiffres et plusieurs inquiétudes. Le Travail Humain 52: 97–116; 1989.

Warr P. B. In what circumstances does job performance vary with age?. Eur. Work Organiz. Psychol. 3: 237–249; 1993.

Warr, P. B. Age and employment. In Triands, H. C.; Dunnette, M. D.; Hough, L. M., editors. Handbook of industrial and organizational psychology. Palo Alto: Consulting Psychologists Press; 1994; 485–550.

WHO. Aging and working capacity. WHO Technical Report Series 835. Geneva: World Health Organization; 1993.

APPENDIX

Accident Rate Ratios (ARRs) with 95% Confidence Intervals by Time Period for Every Age Category, all Accidents Aggregated

Time period	< 30 years	30–39 years	40–49 years	≥ 50 years
1980–83	2.75	2.23	2.55	2.54
	(1.44–5.26)	(1.26–3.96)	(1.44–4.52)	(1.08–5.97)
1984–89	5.97	1.46	2.30	2.63
	(2.95–12.09)	(0.77–2.78)	(1.26–4.19)	(1.10–6.29)
1990–93	1.00	1.00	1.00	1.00

Based on Poisson regressions by single age group with age as independant variable.