

Accident risk as a function of hour at work and time of day as determined from accident data and exposure models for the German working population

by Kerstin Hänecke, Dr phil,¹ Silke Tiedemann, Dipl-Psych,² Friedhelm Nachreiner, Dr rer nat,² Hiltraud Grzech-Šukalo, Dipl-Psych¹

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Objectives Recent studies indicate that accident risk may be a function of hour at work and time of day. Further evidence was sought for these assumptions, along with the answer to the question of whether the risk of accident can be conceived as an interaction between hours at work and time of day.

Methods Data on more than 1.2 million accidents for the year 1994 were provided, all listed according to the time of day and hour at work. Since information about how long each day and at what time of day people work is not available in Germany, different exposure models had to be estimated. For estimating the risk of having an accident relative accident risks were calculated from the ratio of accident frequencies to the exposure data.

Results An exponentially increasing accident risk was observed beyond the 9th hour at work. The relative accident risks differed considerably according to the respective exposure model with regard to time of day. A highly significant interaction effect was found for hour at work by time of day, the percentage of accidents at different hours at work varying according to the particular time of day when work is started. For the 3 “traditional” shiftwork starting times, it was shown that, with later starting times, the relative accident risk increased dramatically beyond the 8th hour at work.

Conclusions Since the results clearly indicate that there are time-related effects on occupational accident risk, more detailed analyses are called for. More elaborated exposure models should be used to assess the efficiency of work schedules with extended workhours, especially under shiftwork conditions. The results also indicate the necessity of recording and providing adequate data bases for such analyses.

Key terms extended workhours, safety, shift work, work time.

Recent results in accident research indicate that the risk of accidents at work is a function of hour at work. Folkard (1) and Åkerstedt (2) both reported an exponentially increasing accident risk beyond the 9th hour at work. Åkerstedt (2) used data of the Swedish Occupational Injury Information System as a basis for his report. He found that accident risk is nearly the same for the first 8 to 9 hours at work. Beyond the 9th hour at work, however, the risk increases considerably. Folkard (1) calculated the relative accident risk from 5 published studies and found it to be doubled after the 12th hour and trebled after the 14th hour. He concluded that the safest system would be based on 6- to 9-hour shifts. But he also claimed that these findings have to be supported by further research, especially to identify the underlying causes.

Although, on one hand, an 8-hour workday is legally widely established (eg, in German law on work time), reality is often quite different. Extended work times and overtime are still widespread. On the other hand, in the United States, Australia, and some other countries, there is a marked tendency to expand work time beyond 8 hours. Twelve-hour shifts are increasingly popular for different reasons. Employers appreciate the economic advantages and employees like the long periods of time-off resulting from the longer hours on fewer shifts. Therefore, the development of accident risk over hours at work is an urgent question, and the efficiency of such work schedules needs to be assessed (3).

At the same time it is also likely that the risk of accidents may depend on the time of day. Åkerstedt (2) found

¹ AWiS Working-Time and Organizational Consulting and Research, Hude, Federal Republic of Germany.

² Carl von Ossietzky Universität Oldenburg, Oldenburg, Federal Republic of Germany.

Reprint requests to: Professor Friedhelm Nachreiner, AE Arbeits- und Organisationspsychologie, Carl von Ossietzky Universität Oldenburg, D — 26111 Oldenburg, Germany. [E-mail: nachreiner@psychologie.uni-oldenburg.de]

a clear indication for a nearly doubled accident risk during night hours, and Smith et al (4) found evidence for an increased risk of injuries during the night shift in comparison with morning and afternoon shifts.

Another question which has not yet been addressed thus far is whether there is an interaction between hours at work and time of day with regard to accident risk. It can be hypothesized that working a 12th hour on a job may differ according to the starting time of the shift (eg, when the 12th hour is at 1800 at the end of a day shift or at 0600 at the end of a complete night shift).

In order to shed more light on these problems, a study was conducted to determine whether accident risk can be conceived as a function of hours at work, time of day, or an interaction of the two.

Materials and methods

One of the main problems of answering questions related to associations between hours at work, time of day, and accident risk is the availability of adequate data bases, especially with regard to exposure towards the risk of having an accident. For this reason, accident frequencies must be analyzed together with adequate exposure data on the relevant population.

There have been no difficulties in obtaining data on the frequencies of registered accidents (leading to an absence of >3 days) from the confederation of workers' compensation boards [Hauptverband der Gewerblichen Berufsgenossenschaften (HVBG), public services and agriculture not included] in Germany. More than 1.2 million such accidents were registered for 1994, all listed according to time of day (24 hours) and hour at work (1st to 12th hour, >12th hour).

Unfortunately, information about *how long each day* people work and *at what time of day* they work is not available in Germany because such data are not registered and no complete or workable national statistics have been collected on these work characteristics. Therefore, suitable exposure models, based on the best available evidence, had to be developed for the comparison with accident rates.

For this purpose different exposure models that could be (cross-) checked for consistency were constructed and calculated from the results of 2 independent surveys on problems of workhours in Germany (5, 6).

The first study (5), conducted in 1992, included data from approximately 5000 employed and self-employed respondents from the Federal Republic of Germany (including the former German Democratic Republic). The second study (6), conducted in 1993, was based on data from 2577 respondents from the employed population (aged 18–65 years) from the area comprising the former West Germany, including West Berlin. [A subsequently

published survey (7) from 1995, including the former German Democratic Republic showed that there was essentially no difference with regard to the number of overtime hours worked between former West and East Germany; therefore the data can be regarded as representative for the whole of Germany with regard to this point.] The samples of both studies proved to be representative. The calculated exposure models based on the data of these studies, although relying on slightly different samples collected roughly 1 year apart, were in good agreement (and moreover proved to be in good agreement with some later published microcensus results for Germany). Therefore, the exposure models can be assumed to be both representative and valid. A detailed description of the rationale and the calculations performed to arrive at the exposure models are included in an unpublished report by Tiedemann.

For an index for comparing the risk of having an accident according to hour at work and time of day, the relative accident risk was calculated as the ratio of the accident frequencies (from the data of the workers' compensation board) to the calculated exposure data of the German working population by the following formula: $\text{relative accident risk} = (\text{accidents [in \%]} \times 100) / (\text{working population [in \%]}),$ percentages being based on the relevant distribution (ie, hour at work or time of day).

Results

Accident distribution

In figure 1 the distribution of registered accidents provided by the HVBG is shown for 1994. It can be seen that the absolute number of accidents is extremely high for people starting their job at 0600, 0700 or 0800, which is the majority of the work force, including day workers, part-time workers, and shift workers, eg, working 12-hour shifts and starting their work at 0600. There is also another small peak for people starting work at 1400, and another very small peak for people starting their work at 2200 to 2400, probably shift workers starting their afternoon or night shifts.

A decrease in accident frequencies at common times for work breaks can be observed (eg, around 0900 and 1200–1300) in other words after different numbers of hours at work, depending on the starting time (eg, for those starting their work around 0700 during the 2nd or 3rd hour and again during the 5th to the 7th hour at work). The same seems to hold for other starting times (eg, for the 5th hour at work for those starting at 1400).

Hour at work

Figure 2 shows an exposure model of the German working population, accident frequencies, and accident risk

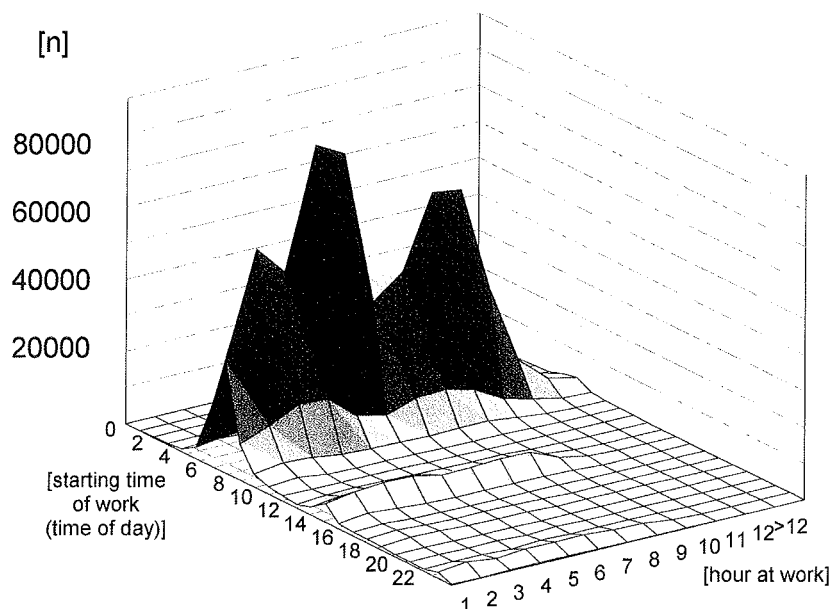


Figure 1. Distribution of registered accidents in 1994 by hour at work and time of day of starting work.

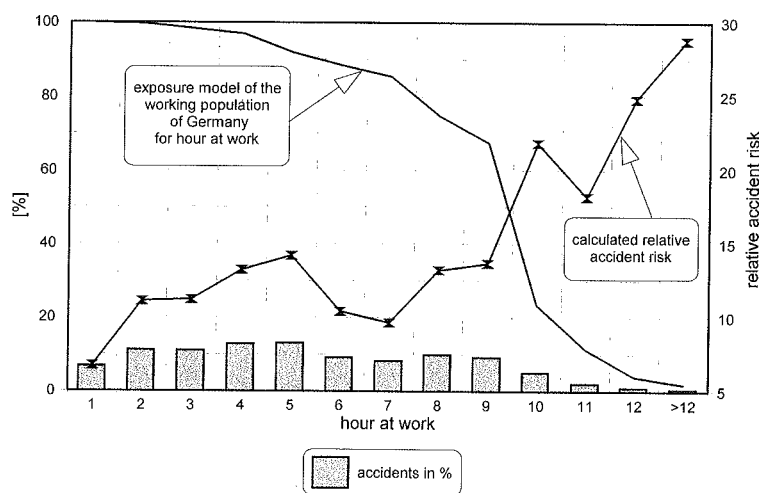


Figure 2. Exposure model of the working population, accident frequencies, and accident risk by hour at work.

by hour at work. According to this model 100% of the employed population works up to 2 hours per day. Thereafter a slight decrease can be seen. Nearly 70% of the population works up to 9 hours per day (including breaks). Beyond the 9th hour the percentage decreases considerably.

The bars at the bottom of figure 2 represent the distribution of accidents from the 1st to the 12th hour at work and for >12 hours at work. The increase in the first 5 hours, a rather even distribution until the 9th hour, and the decrease from the 10th hour are typical for the frequencies of accidents. This distribution has already been reported earlier (8); therefore it can be assumed that the distribution is reliable.

The calculated relative accident risk for hour at work (based on the exposure model and the accident distribution) is also shown in figure 2. It increases exponentially beyond the 9th hour at work.

Time of day

The basis for developing a valid exposure model of the working population over time of day from the available data bases was limited and rather uncertain. A variety of possible exposure models could be constructed. Two were calculated on the basis of the survey data in combination with the distribution of the starting times from the accident data, one as a maximum estimate and the other as a minimum estimate. The effect of a break around noon was taken into account in both models. In figure 3 the 2 different exposure models of the working population and accident frequencies are shown by time of day. It can be seen that, at night and around noon, the 2 graphs are similar. A difference in the estimates can be observed, however, for the hours between 0600 and 1100 and again between 1400 and 1900.

The bars at the bottom of figure 3 represent the distribution of accidents over time of day, according to the

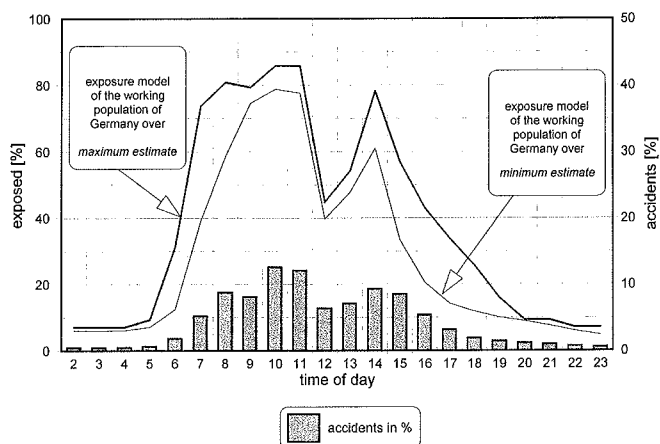


Figure 3. Two exposure models of the working population and accident frequencies by time of day.

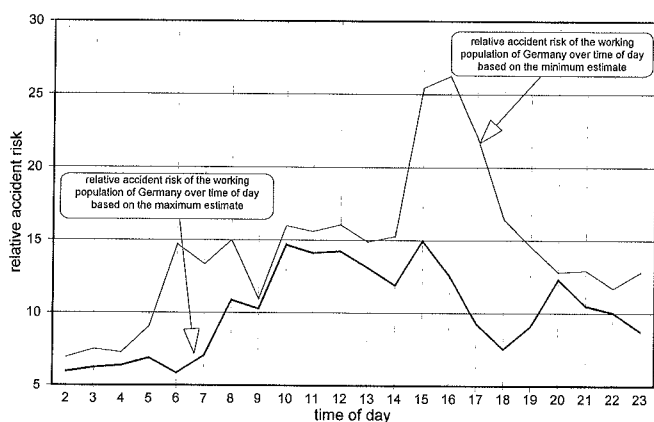


Figure 4. Accident risks for 2 different exposure models by time of day.

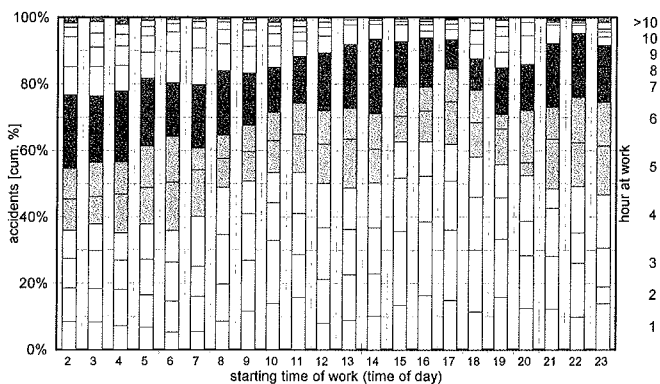


Figure 5. Accident frequencies by hour at work and starting time of work (time of day).

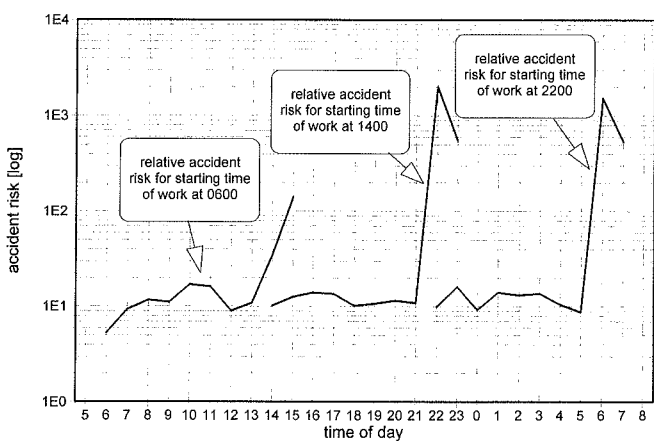


Figure 6. Accident risks on shifts starting at 0600, 1400, and 2200.

data of the workers' compensation board.³ The data show a peak at 1000 and 1100, a drop between 1200 and 1300, and a second peak at 1400 and 1500.

Figure 4 shows the accident risks for the 2 exposure models by time of day. As shown in this figure, the relative accident risks for both estimates, minimum and maximum, differs considerably in the early morning hours and in the afternoon. It should be emphasized that the relatively small differences in the exposure models yielded relatively big differences in the estimated accident risk.

Time of day by hour at work

An analysis for the effect of time of day by hour at work for the absolute accident frequencies shows a clear and statistically highly significant ($\chi^2 = 71\,484.9$; $df = 264$; $P < 0.0001$) interaction for hour at work with time of day.

Figure 5 shows the accident frequencies by hour at work and starting time of work (time of day) in cumulative percentages. Each column shows the distribution of accidents across the 1st to the 12th and >12th hour at work for the subsamples of people starting their work at a given time of day (eg, the first column shows the subsample starting work at 0200 and their distribution of accidents for the consecutive hours at work).⁴ The darkly shaded parts of the column represent, for example, the relative frequencies of accidents in the 7th and 8th hour at work, which means the time of day between 0800 and 1000 for the first column, where work starts at 0200.

With work starting in the evening (1800 to 2000) or at night or in the early morning (2000 to 0700), the percentage of accidents beyond the 8th hour at work is increased, whereas, for people starting their work in the afternoon, the proportion of accidents beyond the 8th hour is rather small. With work starting at 1400 to 1800, on the other hand, the percentage of accidents in the first 4 hours is increased, whereas the accident rate is relatively low for the first 4 hours when work starts at night and in the early morning (0200 to 0700). These results thus suggest that, in fact, there seems to be a difference in the risk of having an accident at the xth hour at work, depending on the starting time of work. This hypothesis would, however, only be testable with an adequate data base for estimating valid exposure models for every hour of starting time of work, which is not yet available.

Although the available data base used for estimating the exposure models according to the starting time of work was rather vague, different models for the

exposure with regard to selected starting times were constructed. As an example, the available data for the 3 "traditional" shiftwork starting times at 0600, 1400, and 2200 were used to calculate exposure models (proportions of people at work). The model (and the accident data) for the starting time 0600 was, of course, confounded by the subsample of people not working shifts (but starting early) or by part-time workers. Therefore, 100% of the working population was not present for the whole 8 hours of the shift. The models for starting times 1400 and 2200 represent, however, 100% of the working population for the first 8 hours, because these starting times are typical for shift workers on 8-hour shifts.

In figure 6 the calculated relative accident risks are shown for shifts starting at 0600, 1400, and 2200, representing the 3 "traditional" shiftwork starting times. Since the risk increases exponentially beyond the 8th hour at work, a logarithmic representation and labeling has been chosen for the y-axis. The results seem to suggest that the exponential increase in the risk of accidents with hour at work is especially distinct with "abnormal" starting times for shifts during the day (eg, those deviating from the "normal" workday).

Figure 6 also shows very clearly another feature of the hypothesized (and for the absolute accident frequencies statistically significant) interaction between hour at work and time of day. There was a marked difference in the risk of having an accident at a certain time of the day, depending on the hour at work (eg, at 1500 when this time was the second hour at work on an afternoon shift, as compared with the 10th hour at work on a morning shift) and the same seems to be true for other combinations of hour at work and time of day as well.

Discussion

The results show that there is clear support for the conclusion already drawn by Folkard (1) and Åkerstedt (2) that accident risk increases exponentially beyond the 8th or 9th hour at work. In addition, this seems to be a rather conservative estimate, as shown by the results of some sensitivity analyses (not presented).

It should also be kept in mind that these results include a wide variety of occupations with different accident risks (eg, from office work to the mining or steel industries). The reported increase in accident risk with

³ Since the data basis for the hours 0000 and 0100 showed inconsistently high values — probably due to the method of assessment — the reliability and validity of these data could not be assumed for these hours. These data were thus excluded from the analyses.

⁴ The labeling on the y-axis as 1 to 10 and >10 hour at work (while the data are grouped into 1st to 12th and >12th hour at work) has only been chosen for the reason of appropriate and readable labeling, because the proportion of accidents, and thus the size of the segments, was very small beyond the 10th hour at work.

hour at work in this case might thus, as well, be regarded as a conservative estimate from such a different perspective, at least for certain industries. It would therefore seem especially interesting to perform similar analyses for certain professional groups or different branches of industry to obtain differentiated estimates of the time-related risk for different occupational conditions. The accident data would be available for such analyses, but there are no exposure data available nor can they be constructed from available data bases. Therefore, such calculations would be impossible at the moment — at least in Germany.

Another weakness of our approach is that many confounding variables cannot be controlled for in these analyses. This lack of control may obscure some distinct effects that would be revealed if one were able to control for such confounding effects as type and amount of work to be done, and presence of supervisory personnel. Smith et al (4) have raised this issue and shown that there are different risks associated with such factors in conjunction with the effects of worktime. In fact, it could be assumed that one of the reasons why no increased risk could be found for night hours in our analyses was the lack of control for such confounding factors.

On the other hand, the results clearly indicate that, in general, the extension of daily workhours to up to 10 hours (and more under certain conditions, *excluding* breaks), as provided by the directive of the European Union and the German law on workhours, cannot be regarded as not increasing the risk of accidents. In fact the opposite applies, as the available evidence clearly demonstrates.

The effects of time of day on accident risk remain unclear. Our results show no increased risk for night hours, neither with the maximum nor with the minimum exposure model. This may be due to the different conditions of work during the day and the night, an observation that is not uncommon (4, 9), and which may be especially true for this heterogeneous population. Such possibilities can, however, only be hypothesized since reliable data are again missing. Once again, a more-detailed analysis with reliable data for specific subgroups would seem urgently required.

Regarding the interaction of time of day and hour at work, our results suggest that it would be worthwhile to expend more effort on such analyses, trying to develop more adequate exposure models (with possibilities of cross-validation) to arrive at more reliable estimates. But again, more adequate data bases for the exposure, at least for being able to estimate the exposure, would be urgently required. Such a data base could be achieved by registering workhours according to their starting time and duration, and, if such a procedure is too expensive, at

least representative samples should be surveyed with questions that deliver the information required from an ergonomic point of view.

To summarize, the results obtained thus far clearly indicate time-related effects on occupational accident risks, which deserve further scientific attention and efforts. However, adequate data bases for estimating the exposure should be provided, even if the results might not be in agreement with the popular requests for more flexibility in the regulation of workhours. From a health and safety perspective, limiting the acceptable amount of hours of work might still make sense, especially for shift workers, as our results indicate. Such a limitation might even be an economically sound approach when the costs of accidents are considered against the benefits of saving personnel or even undermanning, not to mention the question of solving the resulting problems by less efficient (and sometimes even illegal) overtime work.

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References

1. Folkard S. Effects on performance efficiency. In: Colquhoun WP, Costa G, Folkard S, Knauth P, editors. Shiftwork: problems and solutions. Frankfurt aM (Berlin, Bern, New York, Paris, Wien): Peter Lang Verlag, 1996:65—87.
2. Åkerstedt T. Work injuries and time of day — national data. Shiftwork Int Newsl 1995;12(1):2.
3. Duchon JC, Smith TJ. Extended workdays and safety. Int J Ind Ergon 1993;11:37—49.
4. Smith L, Folkard S, Poole CJM. Increased injuries on night shift. Lancet 1994;344:1137—39.
5. Deutsches Institut für Wirtschaftsforschung (DIW). Socio-economic panel data 1992. Berlin: DIW, 1992.
6. Bauer F, Groß H, Schilling G. Arbeitszeit '93. Düsseldorf: Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen, 1994.
7. Bauer F, Groß H, Schilling G. Arbeitszeit '95. Düsseldorf: Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen, 1996.
8. Hoffmann B, Rostek R. Arbeitszeit und Unfallrisiko. Die Berufsgenossenschaft 1995;10:538—42.
9. Monk TH, Embrey DE. A field study of circadian rhythms in actual and interpolated task performance. In: Reinberg A, Vieux N, Andlauer P, editors. Night and shiftwork: biological and social aspects. Oxford: Pergamon Press, 1981:473—80.