LOG-NORMALITY OF DISTRIBUTION OF OCCUPATIONAL EXPOSURE CONCENTRATIONS TO COBALT

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Abstract—In evaluating occupational exposures, the daily exposure levels of a worker are generally assumed to be distributed log-normally between days. When there are many workers in a job group, the individual worker's arithmetic means are assumed to be distributed log-normally. Using the cobalt exposure data in a hard metal factory, these assumptions were examined with the Shapiro-Wilk W test. The hypothesis of log-normality was accepted in all cases, while the hypothesis of normality was rejected in some cases. © 1997 British Occupational Hygiene Society. Published by Elsevier Science Ltd

INTRODUCTION

Occupational exposures (for example, 8-h time-weighted averages: 8-h TWAs) may be different between workers within a job group, and they may also vary between days, for a particular worker. Consequently, even if an 8-h TWA value is lower than the occupational exposure limit (OEL) for the day, it may exceed the OEL on others. Also, even if the mean exposure level for a group does not exceed the OEL, a worker's exposure level may.

In general, exposure concentrations are assumed to be distributed in a log-normal manner (NIOSH, 1977). Several methods based on this assumption have been proposed for evaluating occupational exposures (NIOSH, 1977; Tuggle, 1982; Rappaport and Selvin, 1987; Rock, 1982; Matsunaga et al., 1989; Kumagai et al., 1992). In order to generalize these evaluation methods, the log-normality needs to be examined in various industries. Several investigators have found support for this assumption (Oldham, 1953; Juda and Budzinski, 1964; Kumagai et al., 1989; Water et al., 1991; Rappaport, 1991), but, given their widespread application, further study is needed. Previously, we reported on exposure to cobalt and its variation in a hard metal factory (Kumagai et al., 1995), in this paper, we will examine the log-normality of cobalt exposure concentrations using these data.

METHODS

Dataset

From the cobalt exposure concentrations (8-h TWAs) obtained in a hard metal factory (Kumagai et al., 1995), datasets were selected according to the following criteria.
**Within-worker distribution.** Distribution of 8-h TWAs between days within a worker is denoted as 'within-worker distribution' in this paper. Six workers who were monitored for 10 or more days were selected and the within-worker distributions were examined.

**Semi-between-worker distribution.** The distribution of individual workers' arithmetic means of 8-h TWAs in a group is called 'between-worker distribution.' The true between-worker distribution could not be obtained from our data, because the sample arithmetic mean for each worker might have been inaccurate due to the small sample size and because the sample numbers per worker differed greatly among the workers. Accordingly, the second best method was selected. Briefly, the distribution of the individual workers' sample arithmetic means was examined for each same-number subgroup. The same-number subgroup is defined as a component which consists of 10 or more workers with the same sample number in each job group. This distribution includes a part of within-worker variation as well as between-worker variation, and thus is hereafter denoted as 'semi-between-worker distribution.'

**Subtotal distribution.** 'Total distribution' refers to the distribution of all 8-h TWAs between days among all workers in a job group. The distribution of all exposure data in each job group was not arranged, because the sample numbers per worker differed greatly among the workers, which would bias the distribution. However, the distribution of all exposure data in each same-number subgroup could be examined. Though this distribution does not include all workers in each job group, it contains both between-worker and within-worker variations in each same-number subgroup. In this study, the distribution is defined as 'subtotal distribution.'

**Examination of log-normality or normality**

Log-normality or normality of the datasets of cobalt exposure concentrations was examined using the Shapiro-Wilk $W$ test (Shapiro and Wilk, 1965). If the number of exposure data values in each set was more than 50, the Shapiro-Wilk approximate $W^*$ test was used (Shapiro and Francia, 1972). For subjective evidence of goodness-of-fit to a log-normal distribution, the exposure data sets were also plotted on log-normal probability paper.

**RESULTS AND DISCUSSION**

Table 1 shows the results from the Shapiro-Wilk $W$ test or the approximate $W^*$ test. For within-worker distribution, although the $W$ test resulted in the rejection of the hypothesis of normality in half the cases, the hypothesis of log-normality could not be rejected. For each case in which both hypotheses were accepted, the $W$ value based on the hypothesis of log-normality was larger than that of normality, so that the distribution was closer to log-normal. Figures 1 and 2 show within-worker distributions for a grinding worker (worker b) and a sintering worker (worker f), respectively. The cobalt exposure concentrations gave approximately linear plots on log-normal probability paper. For the other four workers, similar tendencies were observed. Hence the log-normal assumption in within-worker distribution could be
Exposure concentrations to cobalt

Table 1. Examination of normality or log-normality of exposure distribution by the Shapiro-Wilk \( W \) test

<table>
<thead>
<tr>
<th>Distribution</th>
<th>No. of samples</th>
<th>( W ) statistics</th>
<th>Crit. value†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
<td>Log.</td>
</tr>
<tr>
<td>Within-worker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worker a Grinding</td>
<td>37</td>
<td>0.753*</td>
<td>0.949</td>
</tr>
<tr>
<td>Worker b Grinding</td>
<td>35</td>
<td>0.762*</td>
<td>0.986</td>
</tr>
<tr>
<td>Worker c Grinding</td>
<td>12</td>
<td>0.794*</td>
<td>0.933</td>
</tr>
<tr>
<td>Worker d Grinding</td>
<td>10</td>
<td>0.915</td>
<td>0.955</td>
</tr>
<tr>
<td>Worker e Grinding</td>
<td>10</td>
<td>0.936</td>
<td>0.952</td>
</tr>
<tr>
<td>Worker f Sintering</td>
<td>18</td>
<td>0.944</td>
<td>0.962</td>
</tr>
<tr>
<td>Semi-between-worker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaping ( n_i = 2 )</td>
<td>31</td>
<td>0.842*</td>
<td>0.942</td>
</tr>
<tr>
<td>Shaping ( n_i = 3 )</td>
<td>11</td>
<td>0.804</td>
<td>0.923</td>
</tr>
<tr>
<td>Sintering ( n_i = 2 )</td>
<td>12</td>
<td>0.740*</td>
<td>0.843</td>
</tr>
<tr>
<td>Grinding ( n_i = 3 )</td>
<td>27</td>
<td>0.829*</td>
<td>0.965</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press Steel ( n_i = 1 )</td>
<td>15</td>
<td>0.775*</td>
<td>0.951</td>
</tr>
<tr>
<td>Shaping ( n_i = 1 )</td>
<td>11</td>
<td>0.763*</td>
<td>0.970</td>
</tr>
<tr>
<td>Shaping ( n_i = 2 )</td>
<td>62</td>
<td>0.766*</td>
<td>0.971</td>
</tr>
<tr>
<td>Shaping ( n_i = 3 )</td>
<td>33</td>
<td>0.637*</td>
<td>0.979</td>
</tr>
<tr>
<td>Sintering ( n_i = 2 )</td>
<td>17</td>
<td>0.680*</td>
<td>0.950</td>
</tr>
<tr>
<td>Sintering ( n_i = 2 )</td>
<td>24</td>
<td>0.642*</td>
<td>0.934</td>
</tr>
<tr>
<td>Grinding ( n_i = 1 )</td>
<td>35</td>
<td>0.556*</td>
<td>0.939</td>
</tr>
<tr>
<td>Grinding ( n_i = 2 )</td>
<td>81</td>
<td>0.533*</td>
<td>0.984</td>
</tr>
</tbody>
</table>

*The hypothesis of normality or log-normality is rejected at 1% significance level.
†The critical values for each test reflect 1% significance level.

\( n_i \): Number of samples per worker.

accepted. For comparison, the cobalt exposure concentrations were also plotted with a linear axis in Fig. 1. These values formed a convex line, so that the normal assumption was not acceptable.

The results of the \( W \) test of the semi-between-worker distribution are shown in the second portion of Table 1. The test rejected the hypothesis of normality for three cases, but the hypothesis of log-normality was accepted for all cases. Figure 3 illustrates the semi-between-worker distribution (\( N_f = 3 \)) in the grinding group. The plots gave an approximately linear line. The other three semi-between-worker distributions were also found to be linear on log-normal probability paper. These results suggest that log-normality of between-worker distribution may be accepted, because it is considered to be similar to semi-between-worker distribution.

For the subtotal distribution, the \( W \) test rejected the hypothesis of normality in all cases, while the hypothesis of log-normality was not rejected (the third portion of Table 1). Figure 4 presents the subtotal distribution (\( N_f = 3 \)) in the grinding group, showing that the cobalt exposure concentrations gave nearly linear plots. The other seven subtotal distributions were also found to be of similar shape. These results suggest that the log-normality assumption of total distribution may be acceptable, because it seems to be similar to the subtotal distribution.

Our findings suggest that the within-worker, between-worker and total distributions were all approximately log-normal in the hard metal factory. This agrees with previous reports from other investigators (Kumagai et al., 1989; Water et al., 1991; Rappaport, 1991). Water et al. (1991) examined within-worker
Fig. 1. Within-worker distribution of cobalt exposure concentrations in worker b. O: log axis, Δ: linear axis.

Fig. 2. Within-worker distribution of cobalt exposure concentrations in worker f.
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Fig. 3. Distribution of individual sample means among grinding workers with three samples.

Fig. 4. Distribution of all samples among grinding workers with three samples.
distributions in 16 mercury-exposed workers and showed that most of them were approximately log-normal. The total and between-worker distributions among these mercury-exposed workers were also suggested to be log-normal by Rappaport (1991). Rappaport (1991) and Kumagai et al. (1989) found similar results for within-worker distributions in five inorganic lead-exposed workers and five organic solvent-exposed workers, respectively. All of these observations point to the acceptability of the log-normal hypothesis.

CONCLUSION

To protect workers from adverse health effects, exposure conditions should be appropriately evaluated. Such methods based on the assumption of log-normality of the occupational exposure concentration were already proposed. Because the assumption was shown to be appropriate in the hard metal factory, the already proposed evaluation methods can be used.

REFERENCES


