Differences in Eye and Hand Movements of Novice and Experienced Press Operators

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Presses are very widely used in industrial and commercial companies and are often the source of serious accidents occurring during operation. Most of the accidents are due to inadequate training of novice operators. Continuous recordings of eye and hand movements of five novice operators and five experienced operators in press operation were made. Significant difference between novice and experienced operators was observed in eye fixation time, eye movement patterns, hand dwell time, and eye-hand coordination. Also, differences were observed in spatial distribution of eye fixations during the die-closing portion of a stroke. There were no significant differences between novice and experienced operators in the eye and the hand movement time. The results could be used as basic data to establish a guide determining the method and training period to train novice operators.

1. INTRODUCTION

An examination of published data on accidents at work in Korea shows that a significant number of all reported accidents involved presses. Based on the Labor Ministry data, statistics show that the press alone was directly involved in 18.7% of all occupational accidents (Korea Labor Ministry, 1994). From 1990 to 1994, there was a 15.4% increase in the number of accidents caused by the press, although the total number of accidents seems to have decreased since then. The press holds the first place in the industrial hazard machines for frequency of accidents.

In Korea, novice operators having working experience of less than 1 year accounted for 61.8% of the press accidents. Thus, most of the persons involved in accidents have not received adequate operator education training. This is due to the...
fact that many operator education programs are poorly funded and conducted by persons who have had little training themselves. For accident prevention, it is important that novice operators experience appropriate training procedures and that they be evaluated before being assigned to press operation.

Several studies of work evaluation using only eye movements have been performed to improve productivity and safety. The tasks of these studies include vehicle driving (Hella, Tisserand, & Schouller, 1988, 1991; Mourant & Rockwell, 1970, 1972; Robinson, Erickson, Thurston, & Clark, 1972; Shinar, McDowell, Gte, & Rockwell, 1978; Walraven & Lazet, 1966, as cited in Mourant & Rockwell, 1970), various activities of aircraft pilots (Itoh, Hayashi, Tsukui, & Saito, 1990; Wierwille, Rahimi, & Casali, 1985), industrial inspection (Megaw & Richardson, 1979; Schoonard, Gould, & Miller, 1973), VDU work (Yamamoto & Kuto, 1992), and X-ray examination (Kundel & La Follette, 1972).

Kundel and La Follette (1972) found that experienced radiologists detected abnormalities in X-ray with fewer fixations than novice examiners. Walraven and Lazet (1966, as cited in Mourant & Rockwell, 1970) have suggested that a record of drivers' eye movements may provide a better method of assessing driving skill than available methods. Mourant and Rockwell (1972) showed that search and scan patterns of novice drivers were different from those of experienced drivers. In that study, it was found that novice drivers concentrated their eye fixation in a smaller area as they gained driving experience and looked closer in front of the vehicle and more to the right of the vehicle's direction of travel than experienced drivers. Hella, Tisserand, and Schouller (1991) reported that visibility at the driver's stand of lift trucks can be reasonably considered an essential factor in the safety factors of drivers and other employees in workshops where lift trucks are operated.

When using industrial hazard machines such as presses, operators receive information through the eye and they use their hands in operation. The eyes and hands should be properly harmonized if the press operation is to be performed efficiently and safely. Although evaluation of work using eye and hand movements was needed, it has not been studied much because of the difficulty of experimenting in an actual work situation, the lack of measurement equipment, and the complexity of analysis.

This study is to investigate the eye and hand movements that discriminate between novice operators and experienced operators in press operation. The eye and hand movements of well-experienced accident-free operators will result in the development of criteria for good operating skill. If such criteria were developed, they could be used to assess the operators' skill performance during the training period on an objective, quantitative measure of operating performance. Also, increased knowledge of the eye and hand movement may also improve the content of operator training programs.

2. METHOD

2.1. Participants

Five experienced operators and five novice operators participated in the experiment. All five novice operators were male college students whose ages ranged from 20 to 25
years. None had any press and other production machine experience prior to the experiment. However, they theoretically learned press operation in college during one semester. All five experienced operators were males whose ages ranged from 28 to 36 years. They had experience of at least 2 years on the press, with an average of 5 years. None had experienced any industrial accidents. All participants were right-handed young adults with normal visual acuity. They were paid for their time.

2.2. Press and Experimental Apparatus

The experimental system consists of a press, an eye tracker, and a video camera. The overall configuration of the experimental system is shown in Figure 1.

The press consists of an upper and a lower die. The work-piece is deformed by forces between both dies. These forces pose a danger because they may impinge on parts of the operator's body. The press used for the study was a mechanical type of 1 ton force capacity. Two-hand switches were used as a safety device. Both hands must be on the two-hand switches during the closing portion of strokes.

All measurements were made in the following manner. Eye movements were recorded on a video tape by an eye marker recorder (EMMRL manufactured by ISCAN, Inc.). This system operates at a sample rate of 60 Hz and the participant's visual point of regard may be determined with an accuracy better than 1° over a ±15° to ±20° visual angle range. Movements of the right eye were measured, although the press was viewed binocularly. Hand movements were recorded on a video tape using an off-the-shelf video camera. The video camera operates at a sample rate of 30 Hz. Movements of one hand (in this case, right hand) were measured. Eye and hand movements were synchronized and were recorded on a video tape by a Panasonic Digital A/V Mixer.
2.3. Procedure and Analysis

The participants were given a briefing on the nature and purpose of the experiment. They were instructed to emphasize speed and safety equally. There was a training session of 5 min and subsequently a break of 5 min before the start of the recordings. Subsequently, the experiment session was performed for 5 min. The experiment task was a forming task.

Approximately 9,000 frames of eye and hand movement data were collected on a video tape for each of the 10 participants. A frame-by-frame analysis, using a video recorder, enabled the transformation of the raw data into a format required for investigation. This technique gave the location sequences of eye and hand, the fixation number and the fixation time of eye and hand in each zone, and movement time among each zone. From the total number of frames of data obtained from each participant, the first 5,400 frames were used in the analysis.

For the purpose of analyzing the recordings of eye and hand movements, the press was classified into three zones, namely, 1—material container, 2—die, 3—two-hand switches. The error data, deviated ±3 from the mean, were excluded in the analysis as they were extreme and occurred infrequently.

3. RESULTS

3.1. Eye Movements

The eye fixation times for novice and experienced operators are shown in Figure 2. It was observed that the participants stared longer at the die than at the material container and did not stare at the switch. This means that the participants, not looking at the switch directly, utilize their peripheral vision when switching is needed. It is important to have an easily detectable switch because of the poor visual acuity in the peripheral vision. Wierwille, Rahimini, and Casali (1985) reported that the proportion of fixation time for an instrument might be related to the mental workload: The higher the cognitive mental workload, the longer the proportion of the fixation time for instrument observation. Hence, the die might be the most important zone for press operation. These results should be considered when determining the location of each zone in press design.

The mean and the standard deviation of fixation times on the die for novice operators tended to be longer than for experienced operators. The results fit with Schoonard, Gould, and Miller’s (1973) finding that good inspectors are characterized by relative many brief eye fixations. The results indicated that novice operators needed longer time than experienced operators in acquiring necessary information on the die. The Mann-Whitney U Test (U-test) was used to test for differences between novice and experienced operators in terms of the eye and hand movement data. There are significant differences for the mean and the standard deviation of eye fixation times between novice and experienced operators for the die ($p < .0079$, $p < .0157$). There is no significant difference between novice and experienced operators for the material container.
The eye movement times are defined as the time from the time when the eye of a participant starts a zone to the time when the eye of the participant arrives at a different zone. The eye movement times among zones are not significantly different between novice and experienced operators.

The eye movement patterns per cycle of novice and experienced operators are shown in Table 1. Table 1 shows that the eye movement patterns of participants were mostly identified as the material container → die pattern type. Novice operators had a high rate in the material container → die → die pattern type, whereas experienced operators had a high rate in the material container → die → material container → die pattern type. These results indicated that experienced operators frequently stared at the material before they seized it. There are significant differences between novice and experienced operators in the material container → die → die
pattern type (U-test, $p < .095$) and the material container $\rightarrow$ die $\rightarrow$ material container $\rightarrow$ die pattern type (U-test, $p < .015$). There is no significant difference between novice and experienced operators for the material container $\rightarrow$ die pattern type.

<table>
<thead>
<tr>
<th>Eye Movement Pattern</th>
<th>Experienced</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Container $\rightarrow$ Die</td>
<td>55.3%</td>
<td>56.7%</td>
</tr>
<tr>
<td>Material Container $\rightarrow$ Die $\rightarrow$ Die</td>
<td>9.1%</td>
<td>29.9%</td>
</tr>
<tr>
<td>Material Container $\rightarrow$ Die $\rightarrow$ Die $\rightarrow$ Material Container</td>
<td>28.1%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Others</td>
<td>7.5%</td>
<td>7.1%</td>
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</tbody>
</table>

The danger time of press operation is the time when the hands of the operator are on the die during the die-closing portion of a stroke. The spatial distributions of eye fixation during the die-closing portion of a stroke are shown in Table 2. During the die-closing portion of a stroke, novice operators stared frequently at the die, whereas experienced operators stared frequently at the material container. There are significant differences between novice and experienced operators for the material container (U-test, $p < .056$) and the die (U-test, $p < .0317$).

<table>
<thead>
<tr>
<th>Press Zone</th>
<th>Experienced</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Container</td>
<td>50.3%</td>
<td>11.8%</td>
</tr>
<tr>
<td>Die</td>
<td>27.7%</td>
<td>76.9%</td>
</tr>
<tr>
<td>Material Container $\rightarrow$ Die</td>
<td>16.1%</td>
<td>8.0%</td>
</tr>
<tr>
<td>Other</td>
<td>5.9%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

3.2. Hand Movements

The hand dwell times for novice and experienced operators are shown in Figure 3. The hand dwell time was defined by the lapse of time during which the hand of the operator stays within the same zone in the press. It was observed that hand dwell times of the switches for novice operators tended to be longer than those of experienced operators. There is a significant difference in hand dwell time between novice and experienced operators for the switches (U-test, $p < .092$), not for the material container and the die. There are no significant differences for the hand movement times among zones between novice and experienced operators. The hand movement patterns per cycle were mostly identified as the material container $\rightarrow$ die $\rightarrow$ switch pattern type. There is no significant difference between novice and experienced operators.
3.3. Eye and Hand Coordination

According to the results of several studies on eye-hand coordination, eyes have been found almost always to start moving toward the target before the hand (Abrams, Meyer, & Kornblum, 1990; Paillard, 1982). Because eye movement times are quite brief, eyes have also usually been found to arrive at the target before the hand. Paillard (1982) insisted that the information needed for guiding a hand accurately
can only be obtained after the eyes have reached the target. The time difference between the beginning of eye fixation and the beginning of hand dwell in each zone indicated how early the eyes were fixed before the hand reached this zone. This difference in time was defined as lead arrival time. The lead arrival times for novice and experienced operators are shown in Figure 4. It was observed that the lead arrival times for novice operators tended to be shorter than for experienced operators in the material container. There is a significant difference between novice and experienced operators for the material container (U-test, \( p < .01 \)), not for the die.

The time difference between the end of eye fixation and the end of hand dwell in each zone indicated how early or late the eyes started, compared to the starting time of hand in the zone. This difference in time was defined as lead departure time. The lead departure times for novice and experienced operators are shown in Figure 5. It was observed that the eye had started to move before the hand in the material container, whereas the hand had started to move before the eye in the die. In the eye-hand coordination task, the eye started to move mostly before the hand. In the press task, however, the hand started to move before the eye in the die. The results indicated that the eye started after seeing the hand moving from the dangerous die to safety. The lead departure times for novice operators tended to be longer than for experienced operators in die. The results indicated that, for experienced operators, the eye earlier started from the die after the hand started from the die in order to perform next task. There is significant difference between novice and experienced operators for the die (U-test, \( p < .01 \)).

![Figure 5. Lead departure time for novice and experienced operators.](image-url)
4. DISCUSSION AND CONCLUSIONS

The overall goal of this study was to investigate the eye and hand movements that distinguish between novice operators and the experienced operators in press operation. The results can be summarized as follows:

- A significant difference between novice and experienced operators was observed in eye fixation time, eye movement patterns, hand dwell time, and eye-hand coordination. Also, differences were observed in the spatial distribution of eye fixations during the die-closing portion of a stroke.
- There were no significant differences between novice and experienced operators in the eye and the hand movement times.

Characteristics of eye movement in press operation were similar to those in vehicle driving and the inspection task (Megaw & Richardson, 1979; Mourant & Rockwell, 1972). However, we found that, in addition to eye movements, hand movements and eye-hand coordination are the important factors that distinguish between novice operators and experienced operators in press operation.

The results could be used as basic data to establish a guide determining the training method and training period. Fitts and Poser (1967) listed three stages in learning skilled tasks: the cognitive stage, the associative stage, and the autonomous stage. At the end of the training session of this study, the eye and hand movements of novice operators were quite stable because the task cycle time was short. This indicated they had reached the associative stage of learning. Extension to this research is needed and under consideration to know how long and what type of training is needed before novice operators arrive at the autonomous stage.

Also needed is a study that could explain the fatigue effect of the eye and hand movements. However, participant discomfort, the loss of calibration that occurs during a recording due to the poor attachment of a camera to the participant’s head, and the time-consuming data analysis must be solved to meet the aforementioned goals. The method proposed in the study can be applied in many hazardous machines such as rollers and lathes, in which the eye and hand movements are important.

REFERENCES


