693. A study for safety design of electrical machines considering human behavior

M. Okada[a], S. Toyama[b]
Tokyo University of Agriculture and Technology, Nakacho 2-4-16, Koganei, Tokyo, Japan
E-mail: [a] *50010833202@st.tuat.ac.jp*, [b] *toyama@cc.tuat.ac.jp*
Phone: +81-42-388-7207; **Fax:** +81-42-388-7207
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Abstract. Manufacturers have to design machinery considering not only the intended use, but also a reasonably foreseeable misuse, which can lead to product-related accidents. However, manufacturers cannot predict everything the users might do for the machinery. In this study, we have focused on one type of misuse: when the users put their hands inside machinery. Safety mechanisms that deter users from putting their hands inside machinery are required to prevent such accidents. Therefore, in this study we have tried to understand what promotes this action. In this initial stage of our research, we experimented with the visibility and accessibility of an object, and evaluated whether there are related instructions that can affect human behavior.

Keywords: safety designing, risk assessment, human behavior, accessibility, visibility, instructions.

Introduction

Today, people use a lot of kinds of electrical machinery. All these machines have potential safety risks. For production manufacturers to bring these machines to market, they have to design machines to prevent product-related accidents that can cause injury to operators or damage to their property. Therefore, many designers know that it is important to assess the safety risks with such products during the development stage. Moreover, on the subject of risk assessment, some studies have been made to correctly assess safety risks [1-3].

Risk assessment is a general process that ensures product safety. Fig. 1 indicates the order of risk assessment. The process includes identifying potential risks in a machine, assessing each risk and judging whether a risk with the machine is tolerable for market. In the risk assessment process, machine designers have to define the intended use, and identify any reasonably foreseeable misuses of a machine. Therefore, machines have to be designed with both intended use and reasonably foreseeable misuse in mind.

Some people expect machines to have safety mechanisms that prevent product-related accidents even if operators accidentally misuse the machines. These safety mechanisms must be very effective in deterring human behavior that can lead to such accidents. Therefore, the essential solution to avoiding product-related accidents that occur as a result of human behavior may be for manufacturers to understand specific behavior of an operator when using a machine, and to design machines to prevent such potentially hazardous actions.

Therefore, we have tried to understand patterns of human behavior as they relate to the structure of certain machines. In this study, we have focused on the kind of misuse that can occur when users put their hands inside machinery, because many people have been injured as a result of this action. Furthermore, we have tried to understand the types of machine structures which promote this action. Applying principles of human-factors engineering, we have made experiments with how the visibility and accessibility of an object, and whether or not there are related instructions, can affect the aforementioned human behavior. We then have analyzed the results, taking into consideration safety mechanisms of the machines.

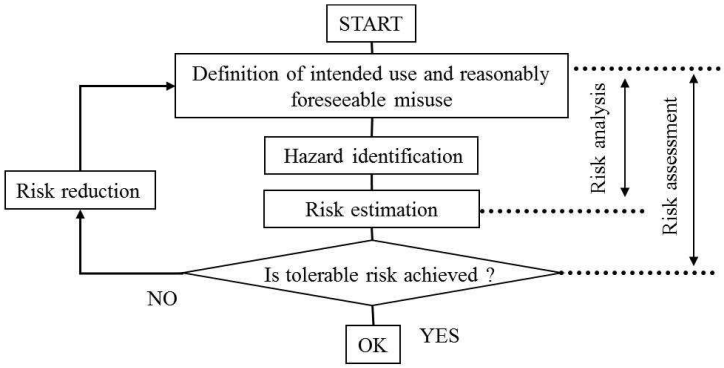

Fig. 1. The order of risk assessment

Experiment

To study human behavior, we examined and observed how persons took an object from inside a box. We have focused on the way that they put their hands inside a box through an opening. Fig. 2 shows a box which was used in the experiments. For the test, we put an object inside a box. A box has an opening in front for people to access the inside. The width of the opening can be adjusted to certain conditions. Moreover, there is a door on the side of a box that can be opened to access the inside. Therefore, in order to get an object from inside a box, subjects could access its inside by putting their hands through an opening or by opening the side door.

In this study, we established three kinds of conditions: the differences between the visibility and accessibility of an object and whether or not there were instructions.

With regard to the visibility of an object, we have studied the differences between the behavior of subjects who could see an object through an opening and those that could not. In case of an invisible condition, subjects could not directly see an object through an opening due to a movable wall between an object and an opening. Fig. 3 shows a profile of this condition.

With regard to the accessibility of an object, we have studied the differences between the behaviors of subjects in relation to the width of the opening.

We also have studied the differences between the behaviors of subjects in relation to whether or not they were given the instruction: “Don’t put your hands through this opening.”

Fig. 2. A box used in the experiments

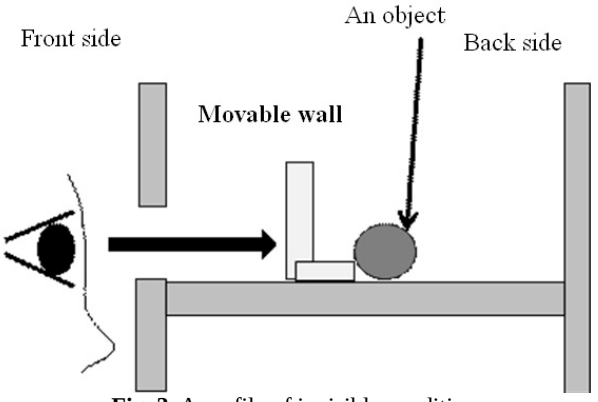

Fig. 3. A profile of invisible condition

Table 1 shows the parameters of these conditions. Based on these parameters, we made twelve kinds of boxes, and we named each box as shown in Table 2.

Before these experiments, subjects took a ball from inside a box several times. These actions helped them to understand that an object was inside a box and that there was a door on the side of a box to access its inside. We also recorded the subjects' actions to reduce any influence that recording their actions might have during the actual experiments.

The experiments were conducted in a closed room. During the tests, the subjects could not see the behavior of other participants, and we recorded the behavior of the subjects. The experiments involved two types of objects; in one case the object was a ball, and in the other case the object was paper.

The details of the experiments are listed below.

- Eleven subjects conducted the experiments.
- All subjects were between the ages of twenty and twenty-five.
- The ball object was a yellow ball that was 70 mm in diameter.
- The paper object was a yellow A3-size sheet of paper that was folded three times.
- In the test room, there were five boxes. Four had a ball inside, but one did not.
- Subjects were told to get four balls as soon as possible.
- Only one subject participated in the experiment at a time.
- Each subject could not see the behavior of other participants during the test.
- Subject behaviors were recorded as they participated in the experiments.
- Subjects responded to a questionnaire about what they felt during the experiments.

Table 1. Test conditions for human behavior and the parameters

	Conditions	1	2	3
I	Visibility	Visible	Invisible	---
II	Accessibility	wide	intermediate	narrow
	Width of a gap	150 mm	75 mm	50 mm
III	Instructions "Do not put your hands inside from this gap"	Instruction	No instruction	---

Table 2. Configurations of boxes in each test condition

Box No.	I. Visibility for an object	II. Width of a gap	III. Instructions
1	I. Visible	II. Wide	III. Instruction
2			III. No instruction
3		II. Intermediate	III. Instruction
4			III. No instruction
5		II. Narrow	III. Instruction
6			III. No instruction
7	I. Invisible	II. Wide	III. Instruction
8			III. No instruction
9		II. Intermediate	III. Instruction
10			III. No instruction
11		II. Narrow	III. Instruction
12			III. No instruction

Results and analysis

We have analyzed subject behaviors while taking an object from twelve kinds of boxes focusing on the three conditions described in Table 1. On analyzing, we have considered the subjects' behaviors for boxes Nos. 1 to 6 as 'objects were visible,' and subjects' behaviors for boxes Nos. 7 to 12 as 'objects were not visible'. Regarding conditions related to the width of the opening, and whether or not there were instructions, we have analyzed the behaviors in the same way as we have done for the conditions for object visibility as shown in Table 2.

In this study, we have focused on the behavior when users put their hands inside machinery. To take the behavior, people need to see an object through an opening, and to put their hands inside through an opening. Therefore, from our experimental results, we have analyzed the two actions separately: 'whether they looked to see an object through an opening in front of a box,' and 'whether they got a ball by putting their hands through an opening.'

Fig. 4 and Fig. 5 indicate the results of the recorded behavior in case when an object is a ball.

First, we have focused on whether test subjects looked to see a ball through an opening in front of a box. Fig. 4 indicates the results of each condition. There are little differences in conditions regarding the visibility of the ball and whether or not there were instructions. On the other hand, we have detected that the wider an opening was, the more likely subjects were to look for a ball through an opening. One of the reasons may be that some subjects judged whether or not to put their hands through an opening when they saw the width of an opening in front of a box.

Secondly, we have focused on whether test subjects put their hands through an opening in front of a box to get a ball after looking through an opening. Fig. 5 indicates the results of each condition. From the results, we can find the three means for structures are effective for deterring people from putting their hands through an opening: visibility, accessibility and instructions. Subjects did not tend to put their hands inside in the case when the object was invisible. Regarding accessibility, in cases when an opening was wide subjects tended to put their hands inside a box through an opening, but in cases when an opening was narrow they tended to get a ball by opening the door on the side of a box. And, instructions were also effective in stopping people from putting their hands through an opening because some people followed these instructions. In addition, from the results, we have determined that the most effective means is for the opening to be narrow in the three conditions.

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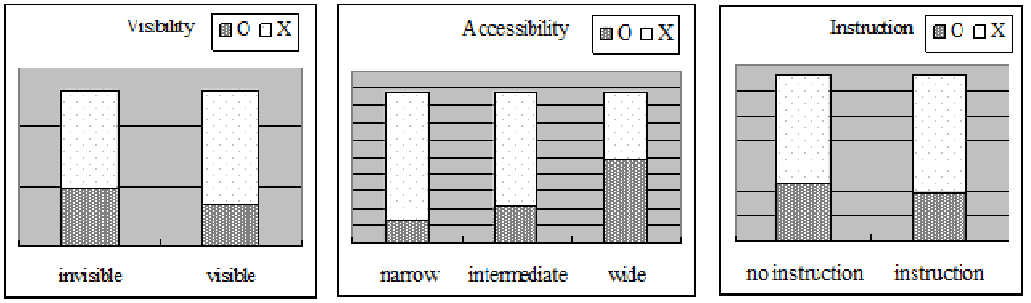

Fig. 4. Results of looking for balls through a front opening in each condition. O: One looked for a ball from a front opening. X: One didn't look for a ball from a front opening

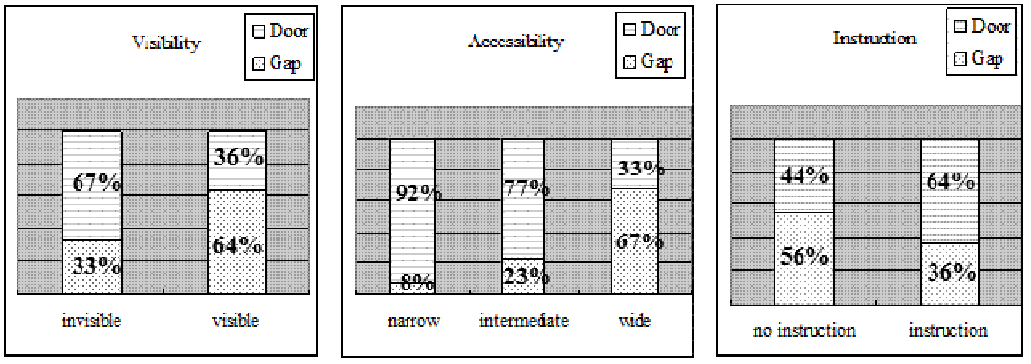

Fig. 5. Rate of how to take a ball after looking from front opening in each condition. Door: One took a ball from a front opening. Gap: One took a ball from a side doors

Next, we have also analyzed the behavior in the case when an object is paper. Fig. 6 and Fig. 7 indicate the results. We have analyzed these results in the same way as for the object being a ball.

First, we have focused on whether subjects looked to see paper through an opening in front of a box. Fig. 6 indicates the results of each condition. As for whether subjects looked through the opening, there are little differences in the conditions of the visibility and whether or not there were instructions. However, the wider an opening was, the more likely subjects were to look for paper through an opening, as same result as in case of a ball.

Secondly, we have focused on whether test subjects put their hands through an opening in front of a box to get paper after looking through an opening. Fig. 7 indicates the results of each condition. From the results, we can find the three means for structures - visibility, accessibility and instructions - are effective for deterring people from putting their hands through an opening as same result as an object is a ball. It was revealed that when the width of an opening was intermediate, 75 mm, subjects tended to put their hands though an opening more often in cases when an object was paper than when it was a ball. In addition, from the results, we have established that the most effective means is for the opening to be narrow in the three conditions.

From the results of using both a ball and a folded sheet of paper, we have determined that difficulty in visibility of an object and in accessibility to an object as well as instructions can be effective in order to prevent people from putting their hands through an opening.

In addition, we have determined that it is the most effective means of difficulty in accessibility to an object under all the three conditions. We have considered that one of the reasons is that when the opening was narrow there are two chances that people would decide

not to put their hands though an opening. First, some people may judge whether they can put their hands though an opening to get an object when they see the gap of an opening. Secondly, some people may judge whether they can put their hands though an opening by actually trying to do so.

And, we have considered that subjects may have judged whether it is easy to put their hands though the opening and whether an object could be easily removed through the opening from the result that in cases of width of an opening being 75 mm subjects were more likely to put their hands though an opening when the object was paper than when a ball. From these results, we have considered that people tend to think about and judge how to get an object from an inside of a box. Therefore, one of a very effective design for a structure that deters people from putting their hands through an opening must be one that encourages people to judge whether to put their hands through that opening during the action.

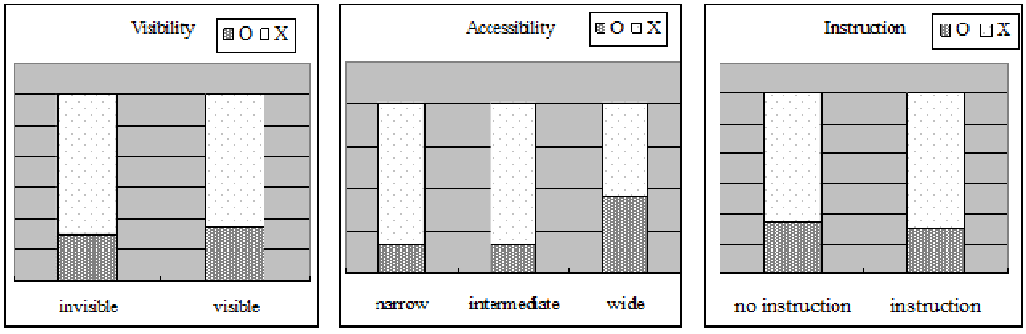

Fig. 6. Results of looking for balls through a front opening in each condition. O: One looked for a ball from a front opening. X: One didn't look for a ball from a front opening

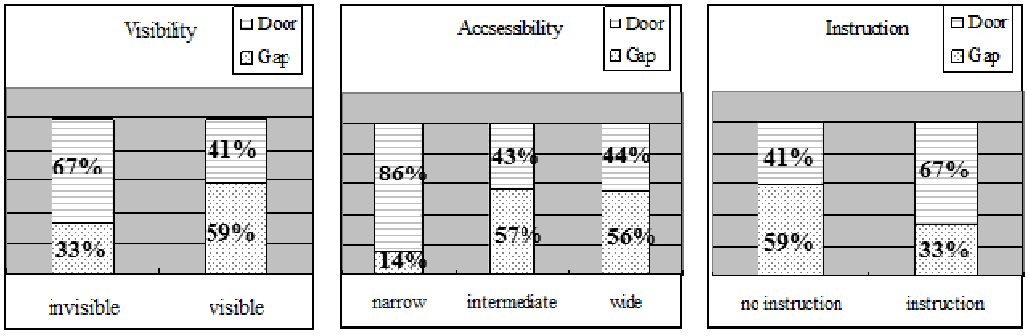

Fig. 7. Rate of how to take a ball after looking from front opening in each condition. Door: One took a ball from a front opening. Gap: One took a ball from a side doors

Conclusions

In this study, we have performed experiments on how the visibility and accessibility of an object, and whether or not there are related instructions that can affect human behavior.

In order to deter people from putting their hands through an opening, the results of our experiments indicate that difficulty in visibility of, and accessibility to, an object as well as instructions can be effective. It was established that the difficulty in accessibility to an object is the most effective in the three conditions.

The results of our experiments suggest that people tend to think and judge how to get an object during the action. Therefore, for safety designing, it must be effective means to design

structures that encourage people to judge whether to take actions that lead to product-related accidents.

In this study, subjects were all around 20 years old. To understand more accurately the tendency of actions of the operators we will conduct more tests using a wider range of ages because electrical machines are used by people of various ages. In order to reduce product accidents that occur as a result of human behavior, we need to improve the design of machinery so that it prevents users from misuse that can cause such accidents. Moreover, we have to better understand the specific behavior of an operator for each machine.

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