EFFECTIVENESS OF A TABLET-PC-BASED SAFETY-TRAINING TOOL FOR CONSTRUCTION WORKERS- AGE-RELATED COMPARISON

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This study seeks to create a tablet-PC-based safety-training tool for residential construction workers and to compare the tool's effectiveness by age. The tool displays four work situations on a tablet PC, including one dangerous situation. Participants choose one dangerous situation from these and learn dangerous situations by repetition. Seventy construction workers participated; they were divided into three groups by age (young, middle-aged, and older). Results indicated that the percentage of correct answers increased for all three groups. Furthermore, the time required for all groups to judge dangerous situations decreased; these results suggest that all groups came to understand the dangers and focused on them more quickly, and that the tool was effective in facilitating comprehension of curriculum content. However, the tool was less effective for the older group than for the other two groups, suggesting the need to improve the tool for older workers.

Introduction

The revised Industrial Safety and Health Law of 2005 requires employers to identify hazards at workplaces and evaluate risks, and to take action to reduce risks. In the construction industry, risk assessment has been promoted in order to prevent work-related accidents. However, even if employers take action to reduce risks at the workplace, it is difficult to reduce risks to a tolerable level because the dynamic factors of the work environment change with the progress of work, and risk varies depending on site. Therefore, it is important that workers themselves learn how to prevent accidents through safety programs and safety training. On Japanese construction sites, workers often receive Kiken Yochi Training, which teaches them to predict hazards in the workplace with team members before beginning work, in order to enhance risk awareness. However, it is difficult to conduct such training on residential construction sites, since only one worker may be at a worksite. Furthermore, an administrator cannot confirm whether the training is being utilized, since worksites are spread over a wide area. Therefore, at residential construction sites it would be useful to have a safety-training tool that a worker can use alone and that allows an administrator to determine remotely whether training is being utilized.

Therefore, this study created a tablet-PC-based safety-training tool for construction workers. When a worker is trained using this tablet PC, the data is automatically sent to a server via the Internet. By accessing this server from another location, administrators can understand and manage the implementation of worker training.

This study seeks to implement safety training of workers with the tablet-PC-based safety-training tool and to investigate the tool's effectiveness empirically. Furthermore, this study focuses on the ages of the workers and compares the tool's effectiveness by age.

Method

Tablet-PC-based safety-training tool

Figure 1 depicts one trial of training using a tablet-PC-based safety-training tool. This trial consisted of a "work situation" that explained in a sentence the work situation of the image to be presented next, a "question" in which four images of work were presented simultaneously, and an "explanation" as to whether the image was incorrect or correct and an explanation. Of the four images in "question," a risk factor was included in only one of the images. After confirming the "work situation," the participant touched as quickly as possible the image in which a risk factor was included. At this time, reaction time and correctness were recorded automatically. The participant then confirmed whether his response was correct and viewed the explanation in "explanation." By repeating this process a few times, the participant learned the risk factors. In this study, the iPad (Apple, MD328J/A) was used to present the images and obtain the data (Cyvision, Ltd., 2013).

Four types of work (work on scaffolding, work with a stepladder, work with a circular saw, and work with a nailer) in which work-related accidents frequently occur at residential construction sites were selected as the themes (The Japan Federation of Housing Organizations & National Institute of Occupational Safety and Health, Japan, 2010). Based on the opinions of labor and safety supervisors for 14 housing manufacturers and the reproducibility of images, eight risk factors were selected per type of work. Table 1 lists the selected risk factors.

One trial was created per risk factor, and eight trials were created per type of work, making one set. In addition, two sets (A and B) were created for training and for verifying effectiveness. Cast, clothes, work location, and angle were changed in order to change the impression of the same risk factors in sets A and B. In addition, the set for training and the set for verifying effectiveness were not decided, and participants were randomly assigned to these sets. Participants learned risk factors by repeating the training set three times. In order to determine whether participants had learned the risk factors, they responded to the validation set. They accomplished all four types of work. In addition, the presentation order of four types of work and eight trials, and the presentation positions of four images of the "question" were random. In this study, 264 images (8 images for practice trials and 4 types of work × 8 trials × 2 sets) were taken for the "question." However, labor and safety supervisors in 14 housing manufacturers determined that an image of the risk factor of "A worker climbs a stepladder while having things in both hands" was inadequate. Therefore, work with a stepladder was one set of seven trials.

Indicator of safety training effectiveness

In studies on safety education in the field of traffic psychology, various indicators have been used to determine the effectiveness of safety training. The first is understanding of the educational content (Shimazaki *et al*., 2012). The second is the transformation of attitudes through education, so that participants' attitudes (e.g., behavior and self-evaluation) change to the safe side (Renge & Kokufuda, 2003; Ohtani *et al*., 2011). The third is the duration of the effectiveness (i.e., whether the effectiveness is ongoing for a few months) (Ota *et al*., 2007; Dommes *et al*., 2011).

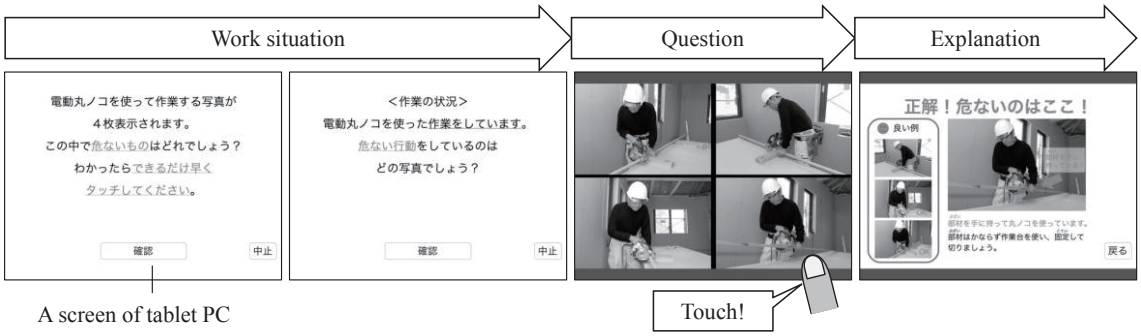


Figure 1. Training with the safety-training tool

Table 1. Risk factors

Work	Risk factors
Work on scaffolds surrounding	1 . A worker is not using the safety belt where the scaffolding and the building frame is away. 2 . Handrail of the scaffolding is removed and left. 3 . When a worker is working, there is a point where the work floor is removed. 4 . A worker moves up and down without lifting equipment. 5 . A material is left in the scaffold. 6 . A worker is working while putting a foot on the handrail. 7 . A worker is working without putting a stopper near the step. 8 . A worker is working while putting a safety belt near his foot.
Work with a stepladder	1 . Stepladder is deformed. 2 . A stay to prevent opening is not used. 3 . A worker climbs a stepladder while having things in both hands. 4 . A worker is working while riding on the top plate. 5 . A worker is working with unreasonable posture on a stepladder. 6 . A worker is working on a stepladder where things are messy. 7 . A worker is working on a stepladder on the step. 8 . A worker get off the stepladder while his back turning to it.
Work with a circular saw	1 . A worker checking out the circular saw that is pluged in before work. 2 . A worker is using the circular saw while fixing the safety cover. 3 . A worker is using the circular saw with a towel hanging from the neck. 4 . A worker is using a circular saw with work gloves 5 . A worker is using a circular saw while holding the material. 6 . A worker is using a circular saw when things are messy on the platform . 7 . Position of the body is not away from the extension of the blade. 8 . A worker leaves a circular saw pluged in after work.
Work with a nailer	1 . A worker checking out the nailer that the air hose is connected with before work. 2 . A worker leaves a circular saw pluged in after work. 3 . A worker does not wear protective eyewear during work. 4 . A worker moves the room while the air hose being connected with the nailer. 5 . A worker's finger was left hanged on the nailer 6 . There are people in the direction a worker hits the nail 7 . The muzzle of the nailer was turned toward another worker. 8 . A worker leaves the air hose connected with the nailer after work.

In this study, understanding of educational content was used as an indicator. Results of the first task and the fourth task were compared to determine whether the percentage of correct answers increased, and whether the time required to judge dangerous situations decreased.

Participants

The participants in this study were 70 male construction workers (carpenters or siding craftsmen) who worked for subcontractors of housing manufacturers. A worker used glasses if he had vision problems. In order to consider whether the tool's effectiveness differed by age, participants were divided into three groups: young, middle-aged, and older. There were 17 men in the young group (age 23 to 35, [mean, SD] 29.8±4.0), 36 men in the middle-age group (age 36 to 50, [mean, SD] 41.6±4.2), and 17 men in the older group (age 51 to 73, [mean, SD] 60.9±5.9).

Procedure

The experiment content and method of operation of the safety-training tool were explained to the participants, who then signed an informed consent form. At this time, participants were told that they could discontinue the experiment if necessary. The simple reaction time was then measured (5 practice trials and 20 test trials). Simple reaction time was measured as follows. A black screen was presented on the tablet PC for a few seconds, and then a white screen was presented. Participants were instructed to touch the white screen as quickly as possible. The time from the presentation of the white screen to the participant's touching the screen was defined as the simple reaction time. Furthermore, the white screen was randomly presented at intervals of 3 to 7 seconds. The participants then received training using the safety-training tool (2 practice trials and 124 test trials). At this time, participants were instructed to touch the dangerous images as quickly as possible.

Result

Comparison of the percentages of correct answers

Figure 2 compares the percentages of correct answers by age. A 3 age × 2 times (1st time, 4th time) ANOVA was conducted on the percentage of correct answers. A significant main effect with age and times was observed for work on scaffolding and work with a nailer (WORK ON SCAFFOLDING age $F(1,67) = 16.32$, $p<0.001$; times $F(2,67) = 11.98$, $p<0.001$; WORK WITH A NAILER age $F(1,67) = 14.77$, $p<0.001$; times $F(2,67) = 4.65$, $p<0.05$). For work with a stepladder and work with a circular saw, a significant interaction between age and times was observed (WORK WITH A STEPLADDER $F(2,67) = 4.19$, $p<0.05$; WORK WITH A CIRCULAR SAW $F(2,67) = 3.14$, $p<0.05$). Results of the post hoc test indicated that for work in scaffolding and work with a nailer, the percentage of correct answers of all age groups increased from the first time to the fourth time (all combinations $p<0.001$). For work with a stepladder, the percentage of correct answers of the older group increased from the first time to the fourth time ($p<0.001$); and for work with a circular saw, the percentage of correct answers of the young group and the middle-aged group increased from the first time to the fourth time (young group $p<0.001$; middle-aged group $p<0.05$). Therefore, the percentage of correct answers of most age groups in all types of work significantly increased from the first time to the fourth time.

In addition, comparison by age indicated that for work on scaffolding, the percentage of correct answers of the older group was lower than those of the other two groups (young and older $p<0.001$; middle-aged and older $p<0.001$); and for work with a nailer, the percentage of correct answers of the older group was lower than that of the young group ($p<0.05$). For work with a circular saw, the first-time percentage of correct answers of the older group was lower than that of the middle-aged group ($p<0.05$), and the fourth-time percentage of correct answers of the older group was lower than those of the other two groups (young and older $p<0.05$; middle-aged and older $p<0.01$). For work with a stepladder, the first-time percentage of correct answers of the older group was lower than those of the other two groups (young and older $p<0.05$; middle-aged and older $p<0.05$). However, the fourth-time percentage of correct answers of the older group did not differ from those of the other two groups. Therefore, the first-time percentage of correct answers of the older group was significantly lower than those of the other two groups, and the fourth-time percentage of correct answers of the older group did not increase to the level of the other two groups, except for work with a stepladder.

Comparison of the time required to judge dangerous situations

A participant was presented with a black tablet screen and told to touch a white screen as soon as it appeared. The required time was defined as the simple reaction time. After several iterations of this, the participant was presented with a screen containing four images and was told to touch the image depicting a dangerous situation as quickly as possible. The required time was then defined as the reaction time. The simple reaction time was then subtracted from the reaction time to obtain the judgment time. In addition, wrong answers were excluded from the data.

Figure 3 compares the time required to judge dangerous situations by age. A 3 age × 2 times (1st time, 4th time) ANOVA was conducted on the time required to judge dangerous situations. For all types of work, the significant main effect with age and time was observed (WORK ON SCAFFOLDING age $F(1,67)=77.65$, $p<0.001$; time $F(2,67) = 4.29$, $p<0.05$; WORK WITH A STEPLADDER age $F(1,67) = 120.08$, $p<0.001$, time: $F(2,67) = 16.05$, $p<0.001$; WORK WITH A CIRCULAR SAW age $F(1,67) = 134.32$, $p<0.001$; time $F(2,67) = 3.96$, $p<0.05$); WORK WITH A NAILER age $F(1,67) = 47.04$, $p<0.001$; time $F(2,67) = 14.22$, $p<0.001$). Results of the post hoc test indicated that for all types of work and for all age groups, the time required to judge dangerous situations decreased from the first time to the fourth time (all combinations $p<0.001$). For work on scaffolding, the middle-aged and the older groups' judgment times were longer than that of the young group ($p<0.05$). For work with a stepladder, the older group's judgment time was longer than those of the young group and the middle-aged group ($p<0.001$). For work with a circular saw, the older group's judgment time was longer than that of the young group. For work with a nailer, the older group's judgment time was longer than those of the young group and the

middle-aged group, and the middle-aged group's judgment time was longer that of than the young group.

Discussion

Effectiveness in understanding educational content

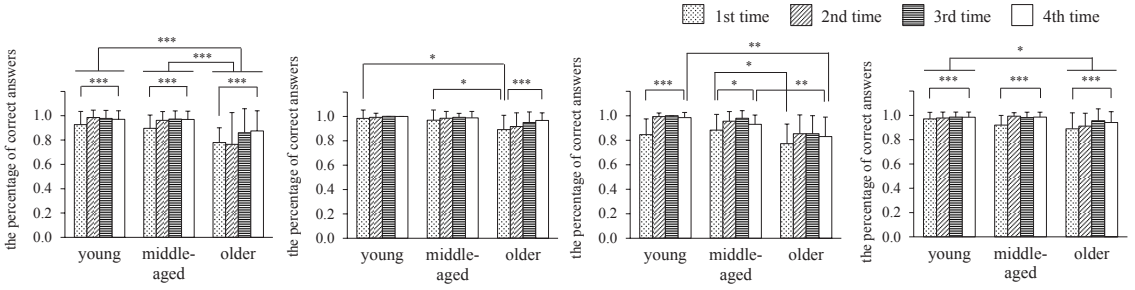
The percentage of correct answers of all age groups significantly increased for work on scaffolding and work with a nailer. The percentage of correct answers of the older group significantly increased for work with a stepladder. The percentage of correct answers of the young group and the middle-aged group significantly increased for work with a circular saw. Furthermore, the time required for all groups to judge dangerous situations decreased. Since different images with the same risk factors were presented between the first time and the fourth time, this result suggests that all groups came to understand the dangers and focused on them more quickly, and that the tool was effective in facilitating comprehension of curriculum content.

The percentage of correct answers of the young group and the middle-aged group did not significantly increase for work with a stepladder. Since the first percentage of correct answers of the young group and the middle-aged group was near 1, this result may be due to the ceiling effect. In addition, the percentage of correct answers of the older group did not significantly increase for work with a circular saw. This result suggests that only three repetitions of training are insufficient for the older group.

Comparison of effectiveness among three age groups

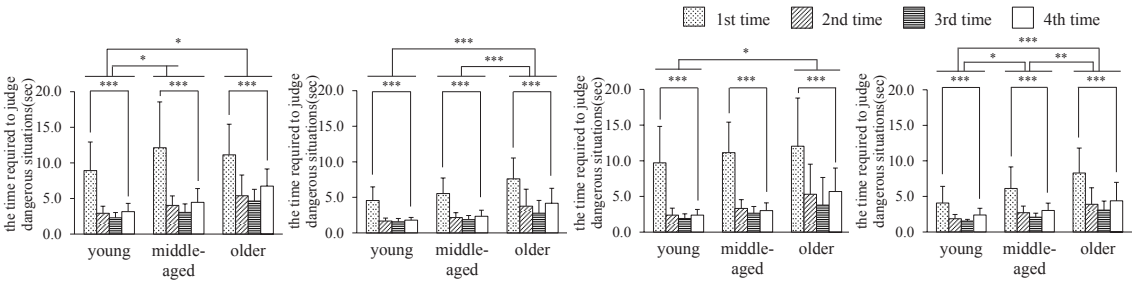
In general, older people are not familiar with information equipment. However, the data in this study were obtained by the very simple reaction of a worker who selects one of four images. Therefore, the effect of familiarity with information equipment was considered to be low. Based on this assumption, we consider a comparison among age groups.

The first percentage of correct answers for the older group was lower than those of the two



*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$

Figure 2. Comparison of the percentage of correct answers of each work group by age



*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$

Figure 3. Comparison of the time required to judge dangerous situations for each work group by age

other groups for all types of work. Since the older group was likely to have long experience and knowledge about safety, this result was contrary to what was expected.

The percentage of correct answers of the older group did not increase to the same level as those of the other two groups, except for work with a stepladder. This result suggests that only three repetitions of training are insufficient for the older group. However, some participants were reluctant to perform the same set repeatedly. Therefore, it is necessary to consider alternative strategies, such as reducing difficulty by a simple image of the "question."

Conclusions

This study sought to create a tablet-PC-based safety-training tool for residential construction workers and to compare this tool's effectiveness by age. The percentage of correct answers of all groups increased. Furthermore, the time required for all groups to judge dangerous situations decreased, suggesting that all groups came to understand the dangers and focused on them more quickly, and that the tool was effective in facilitating comprehension of curriculum content. However, the tool was less effective for the older group than for the other two groups, suggesting the need to improve the tool for older workers.

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