

Improving safety performance of construction workers through cognitive function training

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Abstract

Due to the aging workforce in the construction industry in South Korea, the accident rate has been increasing. The cognitive abilities of older workers are closely related to both safety incidents and labor productivity. Therefore, there is a need to improve cognitive abilities through personalized training based on cognitive assessment results, using cognitive training content, in order to enable safe performance in labor-intensive environments. The provided cognitive training content includes concentration, memory, orientation, attention, and executive functions. Difficulty levels were applied to each content to enhance user engagement and interest. To stimulate interest and encourage active participation of the participants, the difficulty level was automatically adjusted based on feedback from the MMSE-DS results and content measurement data. Based on the accumulated data, individual training scenarios have been set differently to intensively improve insufficient cognitive skills, and cognitive training programs will be developed to reduce safety accidents at construction sites through measured data and research. Through such simple cognitive training, it is expected that the reduction of accidents in the aging construction workforce can lead to a decrease in the social costs associated with prolonged construction periods caused by accidents.

Keywords: Construction Worker, Cognitive Function, MMSE-DS, Flow Theory, level

1. Introduction

The construction industry in South Korea holds a significant position in the national economy and employs a large number of workers in this field every year. Construction workers are required to perform risky and complex tasks on construction sites, demanding high levels of physical labor and cognitive processing to handle a large amount of information. Functional impairments in the process of the information contribute to the occurrence of safety accidents. The accident rate among construction workers is higher compared to other

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industries, highlighting the significance of safety as a crucial issue in construction sites[1]. Therefore, there is a need for education and guidelines focused on safety to address this important concern in the construction industry[2].

In Korea, the construction industry is currently facing the challenge of an aging workforce. Due to higher education levels and population aging, the average age of construction workers on-site is 53.1 years, with 36.7% in their 50s and 24.4% aged 60 or above[3]. Compared to workers in other fields, construction workers have a higher average age. Particularly, older workers in their 50s and above not only experience physical functional decline but also have a higher risk of brain disorders such as stroke and Alzheimer's disease. As a result, they exhibit a higher rate of safety incidents, which can be attributed to a greater likelihood of mild cognitive impairment [4-7]. Ensuring the safety of construction workers engaged in hazardous tasks is a critical issue on construction sites. Currently, there is a need for an objective diagnosis of cognitive abilities and the implementation of appropriate educational guidelines for construction workers to prevent accidents. Therefore, it is necessary to provide education that can improve cognitive abilities among construction workers in order to address this issue[8].

The cognitive abilities of construction workers not only impact accident prevention but also their ability to perform efficiently on construction sites. Cognitive abilities are closely related to the workers' ability, such as concentration, memory, and judgment, when they perform tasks, and are related to their physical abilities. Cognitive abilities are closely tied to the age of the workers and can also influence labor productivity. Cognitive abilities can be improved or their age-related functional decline can be delayed through repetitive training. The introduction of systems to assess and enhance the cognitive abilities of construction workers can contribute to accident prevention and increased labor productivity [9].

Currently, there are several cognitive assessment and improvement training programs being widely used, such as RAPAEL ComCog, CoTras, and Rehacom. However, these programs were developed overseas and may not be suitable for the cultural and emotional context of Korean people. Moreover, their user interfaces may not be easily accessible. Additionally, these programs lack the feature of adjusting the levels of content difficulty based on cognitive abilities, which can result in decreased user engagement and a sense of achievement, making them less suitable for repetitive training. To address these issues, there is a need to develop content that is tailored to the Korean environment and implement a difficulty adjustment feature to facilitate repetitive training.

Therefore, this study investigates the aging workforce and cognitive abilities of construction workers in Korea. It seeks to identify the relationship between cognitive abilities, safety incidents, and labor productivity factors among construction workers, with the goal of finding ways for them to work safely and efficiently. This requires the cognitive training content that is tailored to the emotional context of Korean people and allows for repetitive training and learning. Thereby, this study aims to contribute to the enhancement of construction workers' health, safety, and productivity on construction sites through functional content education and repetitive training by improving cognitive abilities of the construction work forces.

2. Background Theory

MMSE-DS is a simplified cognitive assessment tool based on the Mini-Mental State Examination (MMSE) that has been adapted to fit the social and cultural context of Korea. The evaluation items used in MMSE-DS consist of 19 questions covering various cognitive domains such as orientation, memory registration, attention

and calculation, recall, and language abilities. The evaluation scores are presented in Table 1. The scoring criteria for cognitive impairment are as follows: scores of 24-30 indicate no cognitive impairment (NCI), scores of 18-23 indicate mild cognitive impairment (MCI), and scores of 0-17 indicate significant cognitive impairment (SCI). The optimal cutoff point is suggested to be 16-17, with a sensitivity of 0.768 and specificity of 0.908 [10-12].

Table 1. Main parameters

MMSE-DS questions	score
Orientation	10
Registration	3
Attention and Calculation	5
Recall	3
Language	9

3. Materials and methods

3.1 System configuration

The integrated cognitive function system developed in this study consists of a client, server, and database. The client was developed for Android and PC environments using .NET Framework-based WPF (Windows Presentation Foundation) and Unity3D. The web server was developed using ASP.NET Framework Core, and the database was constructed using MySQL. The content results executed on the PC-based client program are sent to the server and stored in the database. The system configuration is illustrated in Figure 1.

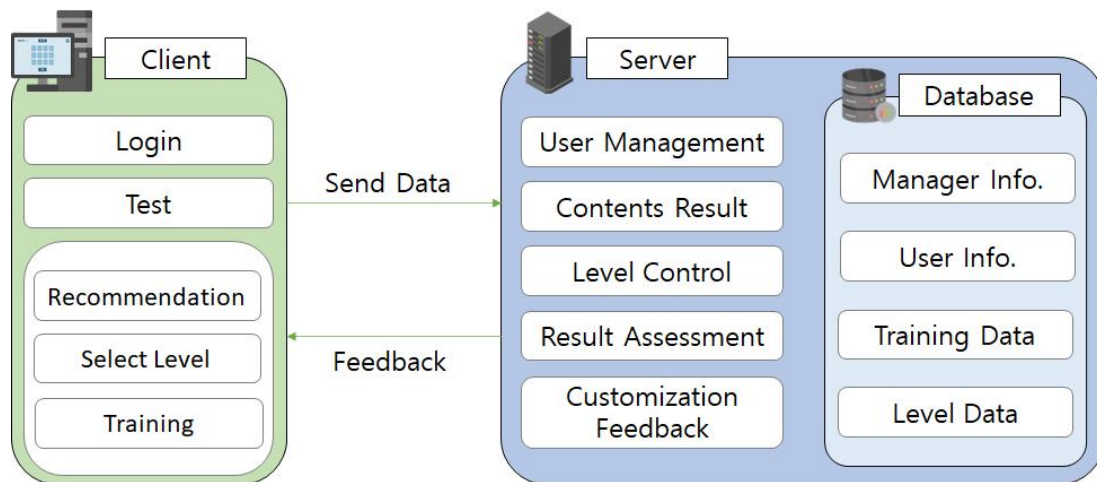


Figure 1. Integrated Cognitive function system

3.2 Simple mental status evaluation program

In this study, we computerized the simplified mental status evaluation tool, MMSE-DS, which is used as a screening tool for assessing the degree of dementia in subjects. MMSE-DS was developed as a program for PC environment, and after user registration, the simplified mental status evaluation program was executed in order to measure the level of cognitive ability to adjust the difficulty and level of training before using cognitive training content. Unlike paper-format surveys, the computerized version takes the form of a mobile app which provides the participants with sentence-based options for answering descriptive questions, shown in Figure 2

(a). For questions involving drawing shapes, multiple shape options were provided to choose from, with the correct model appearing as the answer, shown in Figure 2 (b). After the measurement, the user's result were shown on the screen, shown in Figure 2 (c).



Figure 2. Computerized MMSE-DS

3.3 Cognitive training content

The cognitive training content developed in this study includes a difficulty level feature. Contents with a lower difficulty level than the user's cognitive ability can decrease interest and immersion, leading to a decline in training effectiveness. Conversely, contents with a higher difficulty level than the user's cognitive ability can induce fatigue and result in easy abandonment. Therefore, Csikszentmihályi's Flow Theory was applied as a method to adjust the content difficulty according to the user's cognitive ability. The Flow 4-Channel Model proposed in the Flow Theory categorizes the state of immersion into "Apathy," "boredom," "anxiety," and "flow" based on ability and difficulty[13]. Applying this model to the content, the user's initial experience is classified as "uninterest," situations where the user has high cognitive ability but relatively low difficulty level as "boredom," situations where the difficulty level is high but the cognitive ability is relatively low as "anxiety," and situations where the difficulty level and cognitive ability are appropriately balanced as "flow." The difficulty adjustment pattern based on this model is shown in Figure 3. When participating in content measurement for the first time, the difficulty level is determined based on data obtained from a preliminary aptitude assessment program. After that, using data obtained during training, the difficulty level is automatically applied to the user, allowing for long-term training. The difficulty adjustment is implemented by applying different difficulty levels according to the user's cognitive abilities in each cognitive domain. Areas where the user performs well are set to a higher difficulty level, while areas where the user performs poorly are set to a lower difficulty level.

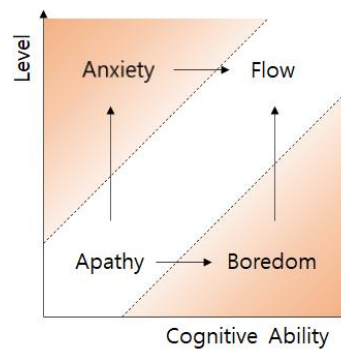


Figure 3. Flow 4-Channel Model

As shown in Table 2, the main categories of cognitive training content are concentration, memory, orientation, attention, and executive functions. Content was developed by dividing it into subcategories according to each category. According to the items, a total of 24 training contents were developed, as shown in Figure 4. The design allows for training of basic subcategories of cognitive functions as well as advanced cognitive function training, depending on the user's cognitive abilities. The design of a user-friendly interface was implemented, taking into account fairness, flexibility, simplicity, intuitiveness, tolerance, and accessibility, to enable user immersion in the training content. The difficulty level of each training content is automatically adjusted based on the user's cognitive ability, and manual adjustment of the difficulty level is also possible based on the user's preference. Content was developed using common subjects encountered in everyday life in South Korea, such as "Bungeoppang" (fish-shaped pastry), and "Whac-A-Mole" game, to enable the users to feel interested in and engaged with the contents.

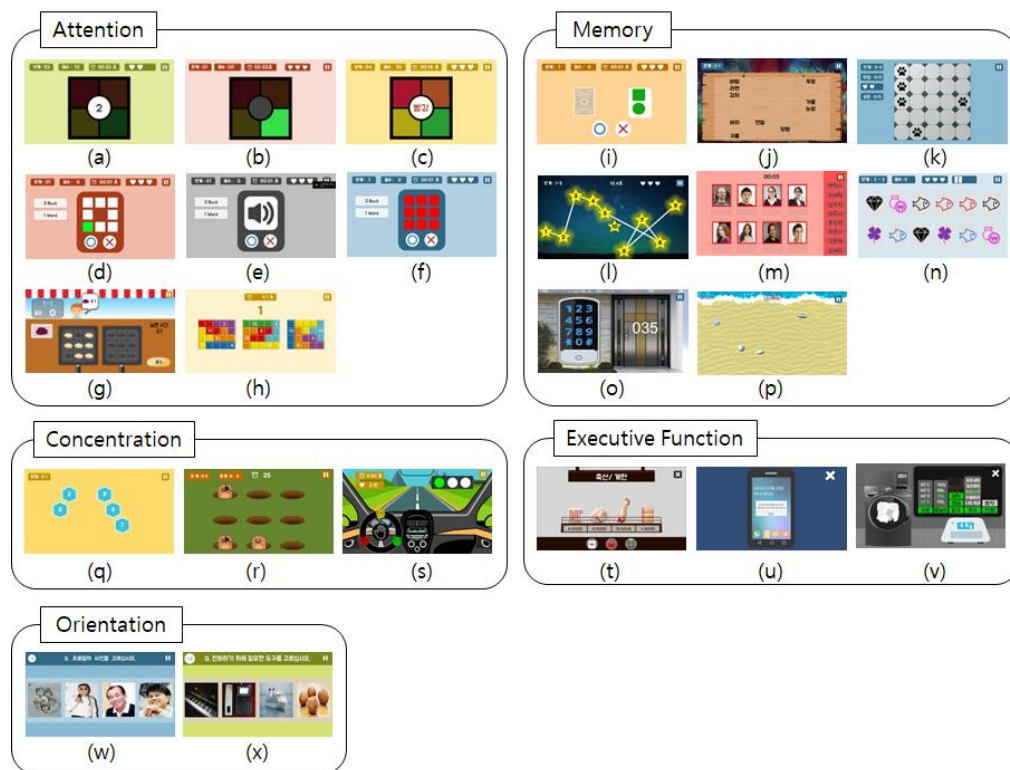


Figure 4. Cognitive Function Contents

Table 2. Content Configuration Table

Main Category	Detailed Category	Contents	Note
Attention	Visual attention	Continuous attention	Figure 4(a)
		Color judgement	Figure 4(b)
		Order judgement	Figure 4(c)
	Divide attention	Location N-Back	Figure 4(d)
		Voice N-Back	Figure 4(e)
		Color N-Back	Figure 4(f)
	Spatiotemporal attention	Bilateral symmetry	Figure 4(g)
	Selective attention	Memory for order	Figure 4(h)
Memory	Picture memory	Card matching	Figure 4(i)
	Word memory	Word guessing	Figure 4(j)
	Working memory	Tile matching	Figure 4(k)
		Connecting the constellations	Figure 4(l)
	Facial recognition memory	Remembering people's names	Figure 4(m)
	Location memory	Matching the same images	Figure 4(n)
	Visual long-term memory	Number memory	Figure 4(o)
	Visual short-term memory	Find the additional picture	Figure 4(p)
Concentration	Eye tracking ability	Eye gaze following	Figure 4(q)
	Visual movement abilities	Whack-a-mole	Figure 4(r)
	Reaction speed	Traffic light	Figure 4(s)
Executive Function	Daily schedule	Grocery shopping	Figure 4(t)
	Daily living	Phone number	Figure 4(u)
		Laundry	Figure 4(v)
Orientation	Human orientation	Human matching	Figure 4(w)
	Object orientation	Object matching	Figure 4(x)

The training results of the content are transmitted to the server and stored in the database, providing visual information in the form of a graph, as shown in Figure 5. Upon completion of the cognitive training content, the radar chart displays scores for each category, as shown in Figure 5 (a). If there are previous training data results available, a line chart is provided to visualize the changes in results over time at a glance, as shown in Figure 5 (b). Accumulated data is used to calculate the difficulty level for the next training session, ensuring the provision of high-quality training.

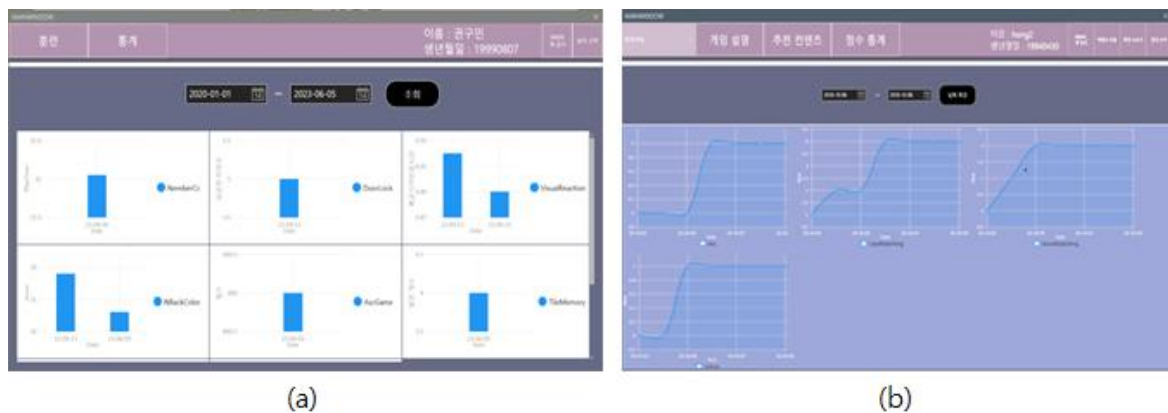


Figure 5. Feedback from Visualization

4. Discussion

The cognitive training content developed in this study was implemented to multiple users, and their data were measured. Each user showed different high and low levels of cognitive abilities in the measured items. Based on the measured results, different training scenarios were automatically applied, adjusting the sequence, items, and difficulty levels of the content. The training scenarios were created for approximately 10 minutes before and after each session. Contents that show relatively lower cognitive abilities were prioritized accordingly to the measured data, and frequently repeated training content was intermittently excluded based on past training information. As the content items, sequence, and difficulty levels continuously changed with each training session, users were able to enhance their immersion and approach the training with increased interest. The training results were provided to users in the form of overall scores and individual scores for each item. Feedback on the results of each item after the training was given to users, enabling them to identify their areas of improvement and understand what kind of training they should focus on.

The results measured using our cognitive training content showed differences based on the participants' education level and computer proficiency. Even among groups with similar cognitive ability scores measured by MMSE-DS, there were differences in the initial measurement scores of the content based on participants' education level and computer proficiency. Computer-based cognitive training content has been proven effective and beneficial in many studies, but there were variations in the measurement and training results data within the same environment due to participants' education level and computer proficiency. Although there were initial differences in the data, the differences decreased as participants engaged in repetitive content training, and further diminished with sufficient time given. It is necessary to consider incorporating scenarios that provide compensation for the initial measurement and training based on individuals' education level and computer proficiency. Further research in this direction seems needed.

We focused our research on the aging workforce in construction sites and measured the content specifically targeting older adults. We selected cognitive function items for the content based on the focus of older adults and developed a measurement and training system accordingly. However, this system primarily emphasizes general older adults rather than elderly individuals specifically in construction sites, indicating the need for cognitive ability weights specific to construction site requirements. It is believed that comparing and analyzing data from general older adults and elderly individuals in construction sites can help extract key characteristics, leading to the identification of measurement and training items specialized for the construction industry. Items with relatively lower weights can be excluded or assigned lower scores, while items with higher weights can be supplemented with additional training content or assigned higher scores, thereby enhancing the specialized content for the construction site.

5. Conclusions

In this study, we designed a cognitive training system to enhance the cognitive abilities of aging workforce in construction sites. To improve the cognitive abilities of construction workers, we classified five main categories and detailed cognitive training content according to the classifications. We provided a feature to adjust the training difficulty based on the user's cognitive abilities through the MMSE-DS simplified mental status evaluation program. Furthermore, we designed the system which can provide feedback on the training results on the screen during training and automatically adjust the level of training difficulty accordingly. The system was also designed to generate user interest and promote long-term engagement in the training. In future studies, it will be necessary to collect and analyze data from actual construction workers over an extended

period of time by using the developed cognitive training system in this study. This will allow for further validation and improvement of the system, including difficulty adjustment and user immersion into content, based on a larger set of validation data.

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