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Visual Information Presentation in Continuous Control Systems using Visual Enhancements

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Every day, millions of people travel by land, water and air. Tracking and a continuous manual control are normally a critical part of any human-vehicle interaction. Also, because aircraft and ground vehicles are often moving at high speeds, the safety implications of transportation systems are tremendously important (Wickens et al., 1998).

In the case of transportation systems which are typical of tracking tasks, more than a million people are killed on the world's roads each year. For example, more than 40,000 people are killed on the roads of the United States each year. Traffic crashes also damage property, especially vehicles. By converting all these losses to monetary values, it is estimated that US traffic crashes in 2000 cost \$231 billion, an amount greater than the Gross Domestic Product of all but a few countries (Evans, 1997). According to a report by the Ministry of Construction and Transportation and the Korea Transport Institute, there were 222,158 accidents in 2004, resulting in 7,013 deaths and 347,661 injured, including all traffic modes, in Korea. As a result, total accident costs added up to 14.5 trillion won which amounted to about 1.86% of Korea's 2004 GDP (Ministry of Construction & Transportation, 2005; Korea Transport Institute, 2006).

The types of systems and mechanisms people control in their jobs and everyday lives vary considerably from simple light switches to complex power plants and aircraft. Whatever the nature of a system, the basic human functions involved in its control remain the same. A human being receives information, processes it, selects an action, and executes the action. The action taken then serves as a control input to a system. In the case of most systems, there typically is some form of a feedback to a person regarding the effects of an action taken. In particular, because tracking tasks which are present in all aspects of vehicle control, including driving an automobile, piloting a plane, or steering and maintaining a balance on a bicycle require a continuous control of something, they are tasks that often involve complex information processing and decision-making activities to determine a proper control of a system, and these tasks are greatly influenced by the displays and dynamics of the system being controlled (Sanders & McCormick, 1993).

In this regard, effective interfaces in various visual displays which are vehicle information systems and aircraft cockpit displays inside an aircraft control room can be important factors to reduce the cognitive workload on human beings during a tracking task like a transportation system.

In this chapter, we describe the fundamental principles about a visual display design and investigate a visual enhancement that is influenced by the performance of visual tasks. Also, we address a representation of the visual information in a continuous control system through a case study related with a visual enhancement.

1. Introduction

1.1 Visual Information & Visual Cognitive Load

The accidents of a human machine system occur by not only the carelessness of human beings who are operators of a system and human causes such as the selection of an inappropriate behavior and action but also factors which are against a human being's ability. These accidents caused by these factors can be prevented by 'engineering changes'. The engineering changes introduce a kind of fully automated system or redesign system in order to exclude people from implementing inevitably dangerous actions themselves or to perform a task that is beyond a human being's ability (Lee, 1998). For example, an airbag to protect a driver or a passenger from the impact of a crash and a collision avoidance system to automatically stop a vehicle in the event of a collision are included in these engineering endeavors. However, many of the engineering changes sometimes cause additional problems for a human operator execution because of technical limits or costs etc. Therefore the mechanical-engineering elements and human factors must be harmonized properly rather than apply an engineering approach that does not consider a human operator's performance capacity and limitation. This approach is called an ergonomics approach and basically pursues this goal: proper harmony of human factors and mechanical factors, and is often called a human-centered design because the fundamental point of this approach focuses on human beings.

One of the important aspects for considering an ergonomics approach is the interaction methods of a human-machine: a bilateral relationship is established by efficiently making a 'Connection' between a human being and a machine within one system. For example, all information that is related to a digression from a normal driving practice must be transmitted to a human's sensory organs through the dashboard in order to drive safely and efficiently in the given road situation, and the driver's efforts for modifying a deviation must be transmitted to the vehicle again. If we think deeply about the interaction of a driver and a vehicle, this interaction may be regarded as a human-machine interaction.

The human being obtains information and controls the system through this interaction. The information which is given to a human being is transmitted by the five senses: sight, hearing, touch, smell, and taste. Especially, the best method for transferring information to humans is visual information. This visual information transfers easily and quickly from a simultaneous perception of a large amount of information to humans. And most of the information among the human senses is inputted through the eyes (Dul & Weerdmeester, 2001). Especially, a situation to the effect that 90% of the information required for driving is visual, is common (Sivak, 1996).

However, this visual information is a burdening cognitive workload by gradually offering various and complex information. So, many researches for a utility of visual information and information that represents a form of this information are performed. For example, if a driver is burdened by abundant or complex contents from navigation information, the performance of driving is worsened because the driver uses information offered by the car

navigation system, evaluates it and makes a reasonable decision. Therefore other navigation informations should be limited as much as possible except navigation information considering positively necessary on the situation. The problem is deciding what information is necessary. Proper visual information can make a task such as driving and piloting better without requiring much capacity of display for a human information processing (Dingus et al., 1989).

1.2 Motor Control

Human operator should convert perceptual environment information in most systems. This behavior should be immediately after perceiving a stimulus. If this selection process of behavior is not accomplished rightly, a human error can be caused. A criterion for selecting a behavior depends on the level of automation. Nowadays, many systems have been automated, but a human operator at least should manually recover systems when an error has occurred in these systems. Therefore, it is necessary to regard a behavior selection through a motor control in order to configure a system by considering a human. Researches of human performance using a motor control have studied two aspects: skill approach and dynamic system approach. Not only do these two-aspects use different experiment subjects and analysis subjects, but also the environment for applying results from these experiments and analyzes is different. A skill approach mainly treats analog motor behavior. The behavior of this type is called an 'open-loop' because it is not necessary to treat visual feedback from the view of a human information processing model. In contrast to the skill approach, a dynamic system approach mainly treats a human's ability which controls or tracks dynamic systems in order to adjust a particular spatiotemporal locus when there is an environmental uncertainty (Poulton, 1974; Wickens, 1986). Most transport controls fit into this category and are called a 'closed-loop' because these controls should treat feedback. These deal with a discontinuous control and a continuous control each, because of these two principles of a control. An open-loop control focuses on 'Fitt's law' through speed-accuracy trade-offs and helps to forecast information for a discontinuous control. In contrast, a closed-loop control offers information for forecasting a continuous control by describing how a human operator controls a physical system.

1.3 Tracking Task

Nowadays, most of the controls, from a simple control in daily life to a complex control in a complex system such as a nuclear power plant, have a closed-loop property. Especially, when facing a complex human situation and a complexity of human-machine system concerns from researches related to a perception movement skill or movement activity of a human, to engineering researches related to a tracking are increasing. This change in domain results from the great influence of three nonhuman elements on the performance of an operator.

- (1) The dynamics of the system itself: how it responds in time to the guidance forces applied
- (2) The input to the operator (the desired trajectory of the system)
- (3) The display, the means by which operator perceives the information concerning the desired and actual state of the system

These elements interact with many of the human operator's limitations to impose difficulties for a tracking in the real world. These limits in particular influence an operator's ability to

track: processing time, information transmission rate, predictive capabilities, processing resources, and compatibility. A human-centered design will be accomplished through considering this aspect in a human-machine system design. Especially, from the aspect of information for estimating a control, a limitation of an operator will be a complement because visual information can transfer easy to humans.

2. Visual Display Design

2.1 Principles of Display Design

A display is a product to play the role of an interface so that visual information which is transferred by a system is cogitated by humans. Therefore, we have to consider a point for a vision, processing visual information and the relationship between human sensory and display properties because the display has an interfacing role between human and machine in order to transmit information. However, only one display tool can not harmonize with all tasks because the properties of a human user who performs a task are various. Main parameters which are essentially responsible for an optimum corresponding physical form of a display and something requiring a task are series of principles about human perception and information processing. These principles are based on all the merits and demerits that human perception and information processing has (Wickens & Hollands, 2000; Boff et al., 1986), and whether the best display has occurred which depends on how well the result of the information analysis applies these principles.

The ergonomics principles for designing a display consist of four categories: principles of perception, principles of mental model, principles based on attention, and principles of memory. These principles include as follows (Table 1).

Category of principles	Case of principles
Principles of perception	Absolute judgement limits Top-down processing Redundancy gain Discriminability
Principles of mental model	Principle of pictorial realism Principle of moving part Ecological interface design
Principles base on attention	Information access cost Proximity compatibility principle
Principles of memory	Principle of predictive aiding Principle of knowledge in the world Principle of consistency

Table 1. Ergonomics principles related to display design

2.2 Visual information presentation

The methods for presenting visual information based on the principles of a display are various. However, as previously mentioned, it is necessary to consider the presentation methods which are used for a task because of the properties of the tasks and human beings. Especially, the presentation method is restrictive in a continuous control system which we

are going to deal with in this chapter. Hence, it is important to find effective methods for reducing the visual load in order to offer visual information. This representative method of visual information is described through a visual enhancement in this chapter.

3. Visual enhancements

Several geometric scaling, enhancement techniques may assist users in their performance and be utilized to improve the interpretability of displays. And these enhancement techniques provide information on the magnitude of the errors which occur when observers are required to make directional judgments using perspective displays or 3D perspective displays. Visual enhancement techniques used in ergonomics are as follows.

3.1 Geometric scaling

The geometric scaling techniques have been applied from three aspects for enhancing visual information. One geometric scaling technique that may be applied to displays is that of a magnification (Wickens et al., 1989b). Repeated observations have been made that objects on a display seen as to be smaller or closer together than they really are (Meehan, 1992; Meehan & Triggs, 1988; Roscoe et al., 1981). As a result, these objects are perceived as being farther away from the observer than they really are. Another geometric scaling technique that has been applied to displays is an amplification of the vertical dimension of a display relative to the horizontal dimension (McGreevy & Ellis, 1991). The horizontal and vertical dimensions of an aviation display are usually asymmetrical. Finally, the technique of nonlinear scaling of an object size in relation to a distance may also be enforced in displays (Wickens et al., 1989b). As a result of the size-distance invariance relationship, images of objects that are very far away will appear as very small on the display.

3.2 Symbolic enhancements

Several symbolic enhancements which enhanced the effectiveness of a display have been used in a display design for an air traffic control in order to transfer spatial information (McGreevy & Ellis, 1985, 1991). The addition of a grid surface or ground plane to a display produced a marked improvement in the perception of the depth. The regular lines of the grid also served as an indicator of the horizontal distance between the objects in the display. A line which connected each aircraft to its true position on the ground plane made the relationship between each aircraft and the grid considerably clearer.

3.3 Visual cue for depth perception

The designer of a display faces a problem which is an appropriate implementation of monocular cues in a display so that it provides a user with an accurate sense three-dimensionality. Concerns that need to be considered include the number of monocular cues that should be selected and which cues to represent. There are usually monocular cues in the natural world such as: (1) light (luminance and brightness effects, aerial perspective, shadows and highlights, colour, texture gradients), (2) occlusion or interposition, (3) object size (size-distance invariance, size by occlusion, familiar size), (4) height in the visual field, and (5) motion (motion perspective, object perception). For example, in a perspective display various combinations of monocular cues may be utilized to create a perception of a

depth. So, we have to consider how these cues interact with each other to create a perspective image.

3.4 Frame of Reference

The frame of reference that is provided to a viewer is also an important consideration in various display designs (Andre et al., 1991; Aretz, 1991; Barfield et al., 1992; Baty et al., 1974; Ellis et al., 1985; Harwood & Wickens, 1991; Olmos, Liang & Wickens, 1997; Rate & Wickens, 1993; Wickens et al., 1989b; Wickens et al., 1994, 1996; Wickens & Prevett, 1995). For example, in an egocentric display, the symbol representing ownship remains stationary while the flight environment moves around it. It has been proposed that the frame of reference that is implemented should be compatible with a viewer's mental model of their movement through the environment (Artez, 1991; Barfield et al., 1995b; Wickens et al., 1989a). Several studies have shown that this mental model may depend on whether a viewer is performing local guidance or global awareness functions.

3.5 Visual Momentum

Visual momentum refers to the visual landmarks that film editors generate to reduce a visual inconsistency among several scenes when editing a film (Park & Woldstad, 2006). The concept of a visual momentum has been expanded to demonstrate the design features of a display system and applied to integrate information among different displays (Woods, 1984; Aretz, 1991). These visual momentums provide perceptual landmarks to help human operators to maintain a cognitive representation among multiple displays.

4. Case Study

This case study was performed to investigate the effects of visual enhancements on the performance of continuous pursuit tracking tasks. Indicator displays with varying visual enhancements were presented on a CRT monitor. Human operators performed manual tracking tasks by controlling the cursor position with a mouse to pursue the motion of a horizontal bar on the indicator display. Quantitative assessments of different display conditions were made by using tracking errors and a modified Cooper-Harper rating as performance measures.

4.1 Experimental Design

We used a within-subject factorial design with three levels of visual enhancement and three levels of task difficulty as independent measures. Three visual enhancements were none visual enhancement (None), a shaded reference bar (Shade), and a translucent reference bar (Shade with line). The shaded reference bar and translucent reference bar were virtual cues overlaid on the horizontal bar of the indicator display, as shown in Fig. 1.

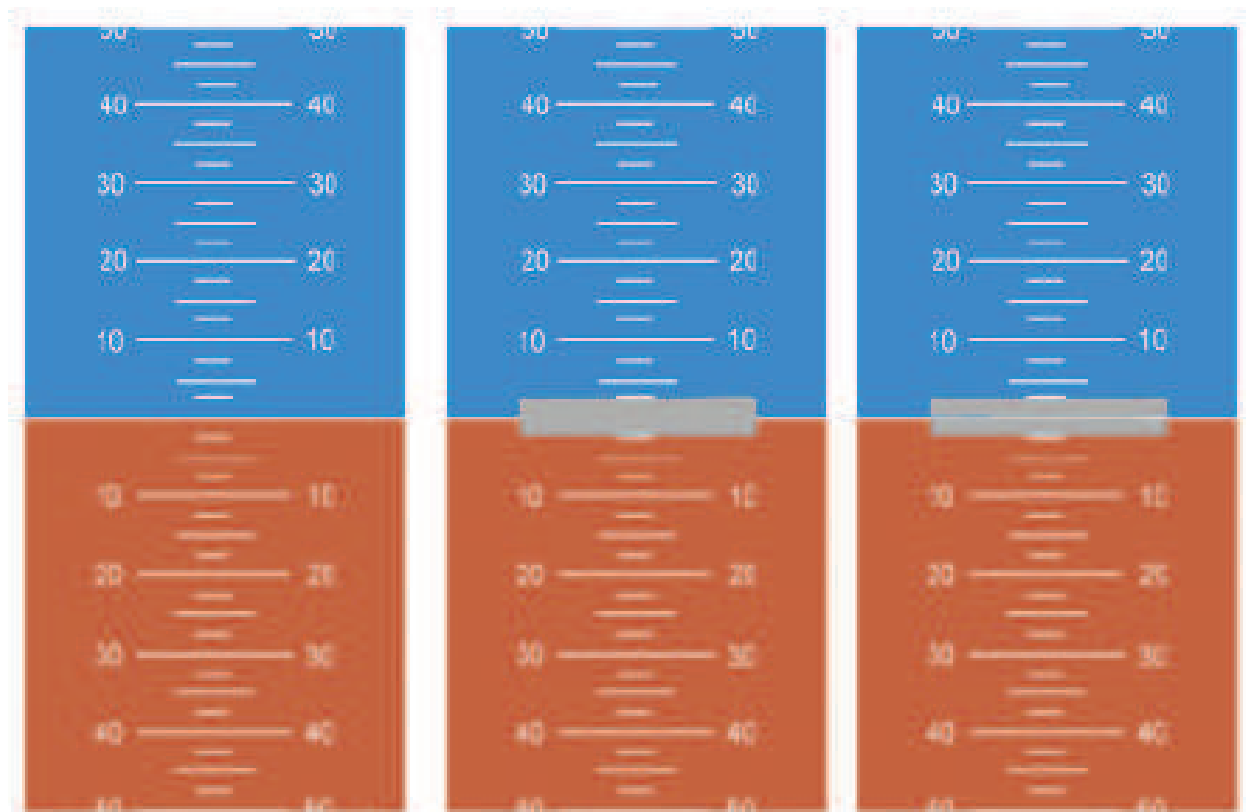


Fig. 1. Indicator displays and visual enhancement cues used in the experiment - From left, none visual enhancement(*None*), a shaded reference bar(*Shade*), and a translucent reference bar(*Shade with line*)

Three levels of a task difficulty were manipulated by changing the speed of the target (i.e., the horizontal bar on the indicator display). The difficulty of a task was adjusted by means of varying a subjects' workload. A preliminary study was conducted in order to tune the difficulty of a task. It was found that reliable changes in the difficulty level could be achieved by varying the speed of the target. As a result, three difficulty levels that were controlled by the speed of the horizontal bar were selected. The average speeds of the target for the low (Low), medium (Medium), and high difficulty (High) levels were 80, 100 and 120 pixels/second, respectively. Dependent measures included tracking errors and subjective ratings of a workload. A tracking error was defined as the total number of pixels between the target and the cursor during the task. The order of the task condition within the blocks was counter-balanced across the subjects, in order to minimize the effect of learning.

4.2 Experimental procedure

Upon arrival for the experiment, participants were instructed to practice the tracking task with all the display configurations. Following an initial practice, participants completed the experimental tasks for the data collection. Participant's tracking data was measured for 60 second/condition. After completing each task, they rated their subjective workload using the modified Cooper-Harper rating scale. They were allowed to rest between trials, if necessary.

4.3 Results

The ANOVA results for the tracking errors showed significant main-effects of a visual enhancement, $F(2, 9)=13.663$, $p=0.0002$ and task difficulty, $F(2, 9)=8.619$, $p=0.0024$ (Table 2). The interaction of the visual enhancement and the task difficulty was not significant, $p=0.1161$.

Source	DF	SS	MS	F-Value	Pr>F
Subject	9	851.571	94.619		
Visual enhancement	2	78.742	39.371	13.663	0.0002*
Visual enhancement ×Subject	18	51.869	2.882		
Task difficulties	2	72.219	36.110	8.619	0.0024*
Task difficulties ×Subject	18	75.416	4.190		
Visual enhancement × Task difficulties	4	9.930	2.483	1.995	0.1161
Residual	36	44.799	1.244		

*: significant at $\alpha=0.05$

Table 2. ANOVA results for a visual enhancement and a task difficulty.

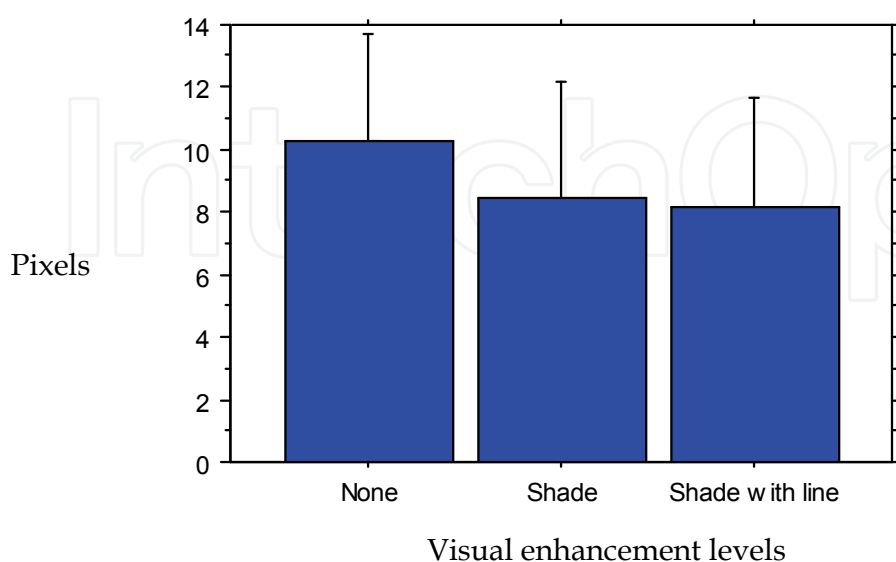


Fig. 2. The means of tracking error for the three visual enhancement conditions (Unit: pixel)

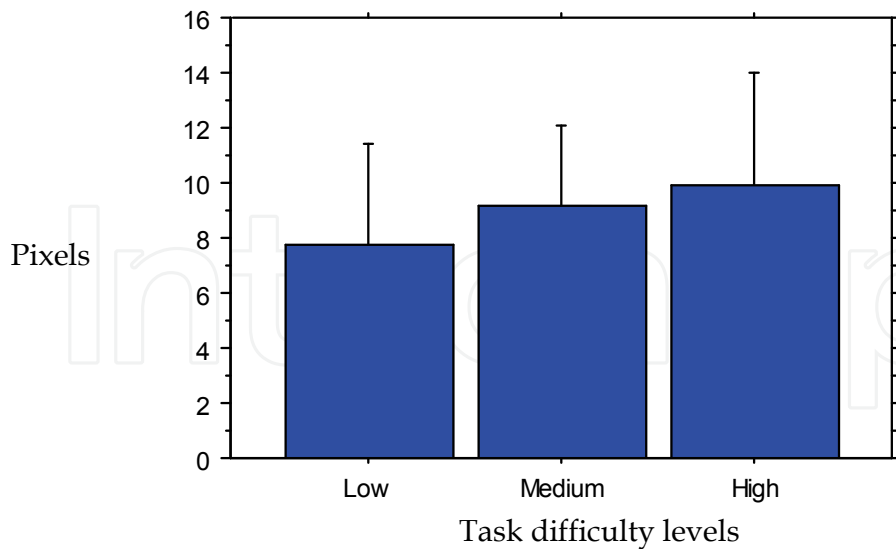


Fig. 3. The means of tracking error for the three task difficulty levels (Unit: pixel)

Student-Newman-Keuls comparisons of the means indicated that the none visual enhancement condition (None) resulted in the largest tracking errors and was significantly different from the shaded reference bar (Shade) and the translucent reference bar (Shade with line). The difference between the shaded reference bar (Shade) and the translucent reference bar (Shade with line) was not significant. The results imply that the shaded reference bar (Shade) and the translucent reference bar (Shade with line) were significant for improving a tracking performance. The tracking task employed in our study requires a frequent use of focused attention. We believe that the visual enhancement cues play an important role in augmenting visual information on a target location. Fig. 2 shows the mean tracking errors for the visual enhancement conditions.

Results of the mean comparisons also revealed that the largest tracking errors were committed in a highly difficult condition (High), followed by, in order, a medium difficulty (Medium), and a low difficulty condition (Low). Fig. 3 shows the mean tracking errors for the task difficulty conditions.

Source	DF	SS	MS	F-Value	Pr>F
Subject	9	71.883	7.981		
Visual enhancement	2	38.756	19.378	4.622	0.0240*
Visual enhancement × Subject	18	75.467	4.193		
Task difficulties	2	42.022	21.011	11.278	0.0007*
Task difficulties × Subject	18	33.533	1.863		
Visual enhancement × Task difficulties	4	3.644	0.911	1.528	0.2148
Residual	36	21.467	0.596		

*: significant at $\alpha=0.05$

Table 3. ANOVA results for the subjective workload.

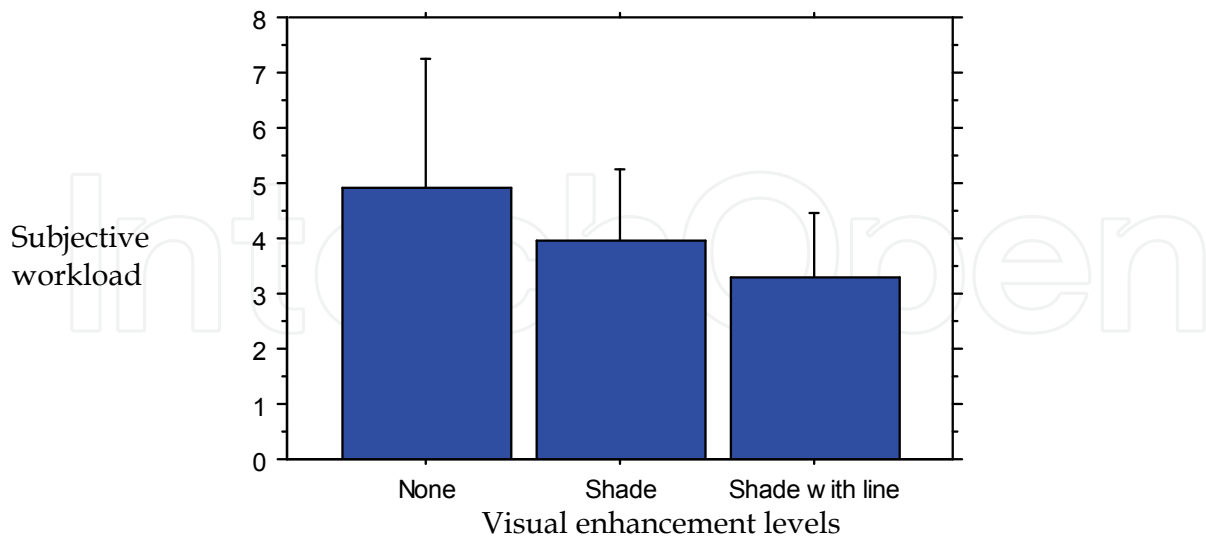


Fig. 4. The means of the subjective workload for the visual enhancement levels

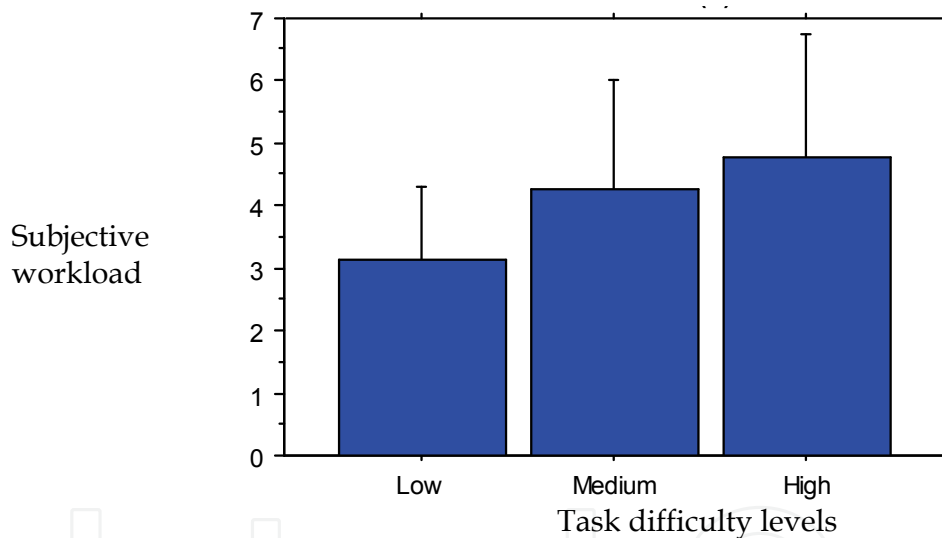


Fig. 5. The means of the subjective workload for the task difficulty levels

The ANOVA results for the subjective ratings of the workload also showed significant main-effects of a visual enhancement, $F(2, 9)=4.622$, $p=0.024$ and task difficulty, $F(2, 9)=11.278$, $p=0.0007$ (Table 3). The interaction of the visual enhancement and the task difficulty was not significant, $p=0.2148$. Student-Newman-Keuls comparisons of the means indicated that the translucent reference bar (Shade with line) was superior to the none visual enhancement (None). However, the difference between the shaded reference bar (Shade) and the none visual enhancement (None) was not significant.

For the task difficulty, performing the task with a highly difficulty condition (High) was judged to be more difficult than performing the task with medium (Medium) or low difficulty conditions (Low).

As previous results have mentioned, the results of ANOVA showed that the performance and subjective workload were significantly affected by the types of visual enhancements and task difficulties. Also, the results of a pair-wise analysis showed that the amount of deviation between the mouse pointer and the horizontal bar moving on an indicator were reduced by tendering visual enhancement cues. Particularly, the performance and subjective ratings were significantly improved in the case of providing a shaded reference bar (Shade) and a translucent reference bar (Shade with line). From the results of comparing the means for each level of the task difficulty, as the task difficulty increased, the degree of a deviation between the mouse pointer and the moving horizontal bar of the indicator were gradually increased. The low velocity (LOW) of a task difficulty was significantly different from the medium velocity (Medium) and high velocity (High). This results support previous findings that virtual cues can be utilized to provide additional visual information for the tasks requiring considerable attention such as a tracking task (Hardy & Lewis, 2004; Park & Koo, 2004).

5. Conclusion

This chapter was intended to identify and quantify the effects of visual enhancement cues on the performance of continuous control tasks such as tracking tasks. Also, we investigated the types and utilities of visual enhancements as visual aids that improve a performance and offer spatial information. Especially, we have indentified that various visual enhancements improve not only a performance but also the possibility of an error through a case study.

The findings of this chapter are applicable to the design of a head-mounted display (HUD) in the context of virtual environments. These findings can also be used as guidelines for designing visual displays for a continuous control system accompanied with a high speed manipulation such as those found in automobile and aircraft systems. Especially, the results of this case study could be applied to design the guidance for the information representation in an information system based HUD such as a Smart car which is an IVIS (In Vehicle Information System) developed by GM motors and Carnegie Mellon University.

In this chapter, when the continuous control tasks were performed through visual enhancements, it was assumed that the participants received visual cues from the same point of view. However, it didn't consider factors such as a depth perception and a pattern recognition of the subjects who were the main recipients of the visual information. Further studies are needed with considerations on the cognitive properties.

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