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Design and evaluation of military geographical intelligence system: An ergonomics case study☆

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ABSTRACT

Rapid developments in detection technology led to the extensive use of new military geographical intelligence systems (GIS). These systems were developed to support military tactical and strategic operation by data collection, processing, analysis, and distribution. This paper reports a case study of ergonomic intervention on the design of GIS. In particular, effects of icon type, icon size, and map background clutter are discussed. This design was specifically used to enhance surveillance performance in the use of interface. Twelve participants carried out a visual search task using the mock GIS. The best surveillance performance was obtained in an interface with large icons and topography not displayed (TND) map background clutter. The results recommended an improved GIS interface design and help interface designers to create efficient and comfortable interfaces for the reduction workload of surveillance radar operators.

1. Introduction

Effective educational initiatives in the ergonomics of human computer interaction (HCI) are concerned with the interaction between human performance and system design [1–4]. Some ergonomic specialists compiled guidelines to help occupational health personnel, who do not have formal qualifications or training in ergonomics, in industrially developing countries [5–9]. Therefore, ergonomic interventions directed at design improvements can improve personnel learning and training performance [10–14]. The previous applications of educational initiatives in the ergonomics of HCI were utilized to assess the learning and training efficiency of personnel monitoring military maneuvers and scheduled flights [15–17]. Operators in these environments work with computerized systems that integrate various sources of information from the field [18,19]. This information must be extracted rapidly and precisely to identify potential dangers [20–22]. The ergonomic interventions have been concerned with how design display characteristics influence variability in the learning and training performance of users in the system [23–25].

A limited number of studies evaluated ergonomic intervention in military workplaces, although some of them reported surveillance performance in the use of radar interface [16,26,27]. The present study investigates a case of ergonomic intervention on geographical intelligence systems (GIS) design that is determined by the icon type, icon size, and map background clutter to enhance surveillance performance in the use of interface. The completion time, accuracy and physiological measures were used in the experiments to understand surveillance performance and cognitive pressure of human beings in response to an external stimulus. The results of this ergonomics teaching case study may be important in laying the groundwork for the improvement of the ergonomics interface design of GIS and determining the learning and training effects of surveillance radar staffs.

Humans who have shifted their role from manual labor to maintenance supervisor monitor complex interfaces through an integrated visual display terminal (VDT) [28]. Staff members who use computerized systems must monitor these interfaces while being exposed to increased mental stress to remain vigilant [29,30]. Thus, most integrated interfaces have graphical user interfaces (GUIs) that reduce mental workload to a greater extent than a traditional text interface [5,19,31–33]. GUIs can offset position restriction in space and present meaning in an outline form. Icons are used in GUIs in various ways and one of the most common representations of objects recognized by the operating system and users [34–36]. GIS comprises a set of data such as natural resources, water resources, vehicle routing, travel problems, and traffic planning. It uses one kind of iconic system that is growing rapidly [14,37] and can be used for battlefield management, sonar detection tasks, and control task of a main control room. Computerized systems in GIS interfaces integrate the above-mentioned information

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from various sources. Operators must carry out geographical data analysis, assessment, and decision-making in a short time. However, military or civilian forces often encounter great difficulties of unknown environmental orientation in GIS, which makes the interface of the GIS one of the most important factors in reducing the operators' workload and preventing safety-related accidents [38,39]. The vigilance of surveillance radar staff has been influential in incorporating workloads into GIS interface learning and training.

The use of graphic software has increased rapidly and created new problems for the interface design in workplaces. Most workstation-ergonomics interventions focus on the musculoskeletal disorders (MSD) and visual problems [40,41]. Work compatibility or postural stress produced by poor workstation ergonomics results in MSD [42–46]. Many hours of computer usage and high work demands are associated with various visual problems [16,26,47–49]. Ergonomic improvements, interface redesign, and education are recommended as primary solutions for the prevention of problems at work using a VDT [50,51].

2. Material and methods

An experiment which was mainly about the ergonomic intervention GIS design was adopted to gain an in-depth and comprehensive understanding of human learning and training performance of surveillance radar staffs in this case study. The experimental sequence took approximately one hour. The participants, experimental setup, calibration, procedure, and data analysis are described in the following subsections.

2.1. Participants

A total of 12 participants (eight men and four women) were ex-service men and women with at least 3 years of experience using computers. They are aged between 23 and 32 years (M = 26.7, SD = 2.9). They are employees of the National Chung-Shan Institute of Science and Technology, which has over 8000 employees and is the primary research and development center for various weapons systems and the system interface of Taiwan. They received a monetary reward for participating in this study. All participants had a corrected visual acuity of 0.8 or better and normal color vision. Each subject signed a letter of consent before the experiment. The participants adapted to the ambient illumination for 20 min before starting the experiment. The participants were instructed to avoid VDT work for at least 3 h before the experiment to prevent visual fatigue.

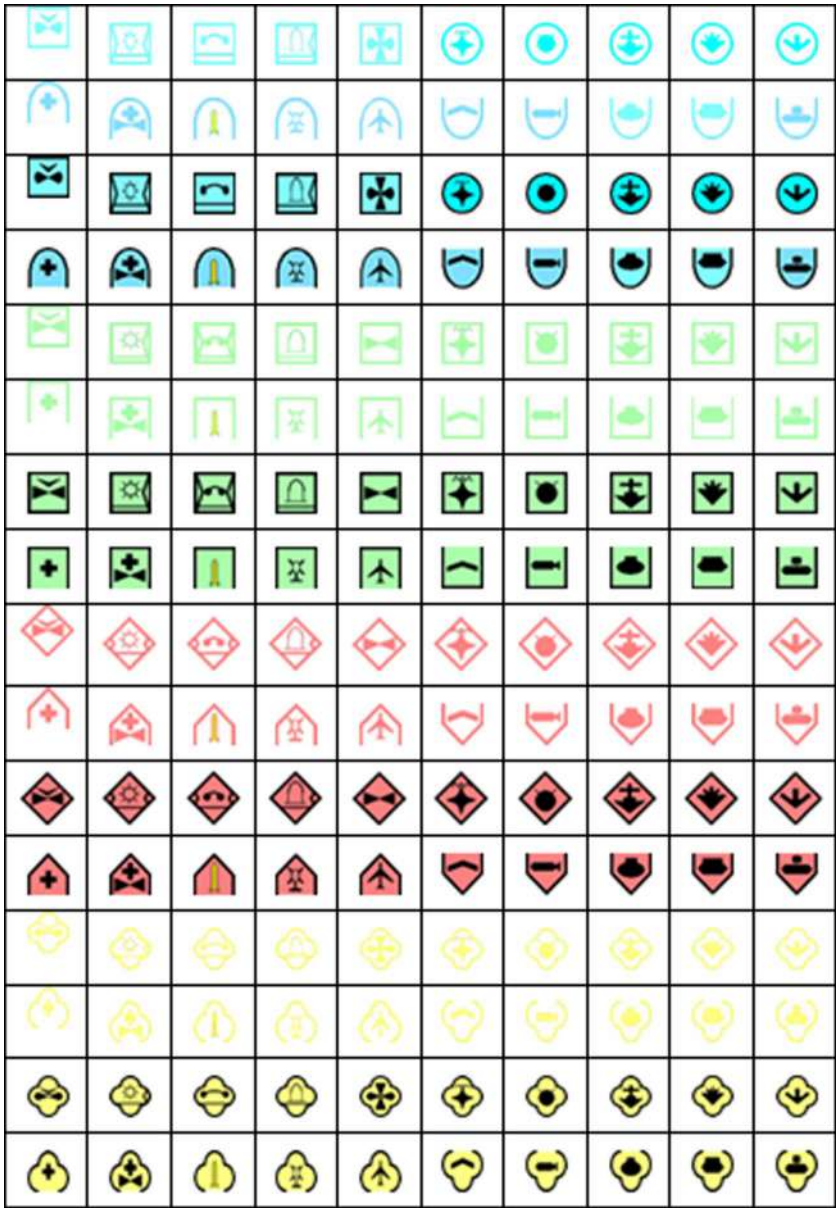

Fig. 1. All the specific icons of Military Standard 2525b consist equally of hollow and filled types in red, blue, green, and yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Apparatus

Before starting the experiment, participants took the color vision test using an Optec 2000 tester and a visual acuity test using Topcon-acp.8 vision tester. Participants then executed the GIS search tasks. GIS tasks involve detecting signals that occur infrequently and unpredictably. The operators usually lose vigilance when few external stimuli kept them alert. A growing number of physiological measures are widely used to assess human performance in response to an external stimulus [52]. The experiment consisted of two main parts. First, the participants were tested using a galvanic skin response (GSR). Second, participants were tested using pupil diameter test instruments. The stimuli were presented on a CHIMEI CMV T38A 21-inch color Liquid Crystal Display monitor with a display resolution of 1280 × 800 pixels at a refresh rate of 60 Hz. The monitor was calibrated with a Minolta CS-100 chroma meter. The monitor was warmed up for 2 h before the experiments began.

2.3. Experimental design

An experiment was designed to evaluate the effects of enhancing surveillance learning for the use of interface in the GIS. This experiment employed a three-factor within-subject design. The independent variables were icon types with two levels (filled and hollow icons), two kinds of map background clutter (topography displayed (TD) and topography not displayed (TND)), and icon sizes with three levels (40, 60, and 80 min of the visual angle with an observation distance of 50 cm). The dependent variables were completion time, accuracy, GSR, and pupil diameter. The completion time and accuracy were standardized measures designed to predict the visual search performance of participants. The GSR and pupil diameter were used to validate the learning and training effects of the cognitive load levels on the participants. The test comprised 80 simulated radar interfaces. Each participant must complete all interfaces in a random sequence. The analyses of variance were used to detect a significant difference among variety.

2.4. Experiment protocol

The experiment was conducted in a windowless laboratory. The wall of the laboratory shielded the participants from external light and sound source. The indoor noise index was manipulated to be lower than 45 dB. The laboratory temperature was kept at 23 ± 3 °C. The desk height was 60 cm, and the chair height was 42 ± 5 cm. The ambient luminance level of the laboratory was maintained at 50 lux to prevent glare or reflection, which would influence participants in this experiment. A simulated geographical intelligence workstation was set up in the laboratory. The environmental illuminant was a diffused light source from a fluorescent tube. The illumination of the laboratory simulated the conditions of geographical intelligence in battlefield management, sonar detection tasks and control task of a main control room.

2.5. Procedure

Common symbology forms the basis of GIS. The chain of command

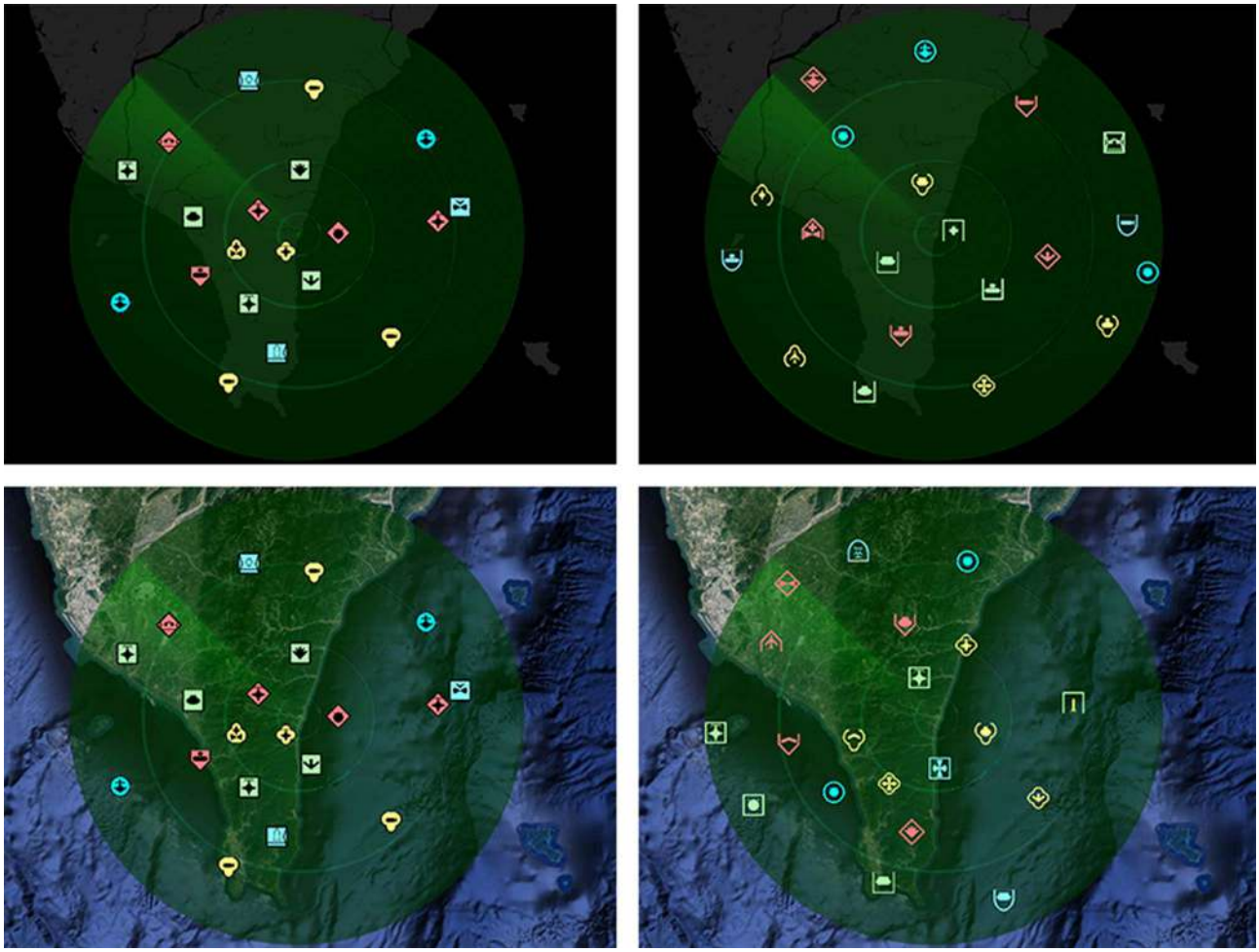

Fig. 2. Mock GIS test program with an icon size of 80 min. The map background clutter is composed of TND (above) and TD (below). The experimental interface comprises icons of filled (left) and hollow (right) types.

system that combines command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) is a key supervisory control apparatus in a real battlefield [53]. The C^4ISR interfaces collect and integrate all kinds of information and then translate that information into a common and meaningful symbol for real-time feedback to all GIS users. The symbology of the GIS must be unanimous, adequate, and identifiable to avoid misunderstanding the symbols. The common war-fighting symbols of "Military Standard 2525b," [54] which represent tactical situations in war and other dangerous situations. The symbols of 2525b were adopted as the icons used in the simulated GIS of this experiment as show in Fig. 1. All specific icons consist equally of hollow and filled types in red, blue, green, and yellow. A simulated GIS test program was built by the software of SR Research Experiment Builder based on the rules of "Military Standard 2525b." The red icons in the test program represented the hostile, suspect, or faker targets; the blue icons represented a friend or friendly targets; the green icons presented neutral targets (neither friendly nor hostile); and the yellow icons indicated unknown or pending targets. An example of the test program interface is shown in Fig. 2. Each experimental interface comprises 20 icons (equally divided into foregoing four colors), which participants could use to search for designated icons. The different experimental interfaces were displayed to participants randomly.

3. Results

Several interesting findings of the learning effects emerged from this experiment. However, this study focused on the design factors of GIS in terms of the icon type, icon size, and map background clutter. ANOVA was used to assess the effects of independent variables on learning and training performance in terms of completion time, accuracy and physiological measures. The ANOVA significance level was set at $p < 0.05$. The results are summarized below.

3.1. Completion time

ANOVA indicated significant main effects of the map background clutter ($F = 3.99$, $p = 0.46$) and icon size ($F = 56.05$, $p < 0.01$) on completion time, as shown in Fig. 3. The interaction effect between icon type and icon size was significant ($F = 3.90$, $p < 0.05$), as shown in Fig. 4. However, the main effect of icon type was not significant. The interaction effects of map background clutter with icon type and icon size were also not significant. The results of the experiment showed that the line diagram Fig. 3(A) declined gradually after the icon size of 60 min. The icon size of 80 min exhibited a shorter mean completion time. The map background clutter line diagram Fig. 3(B) showed that participants needed less completion time on the TND background. ANOVA was conducted and showed in Fig. 4 to evaluate the speed with which participants identified hollow targets. The results were then compared with those of filled targets under a large icon size condition. However, the results for small versus large icon size conditions were contradictory.

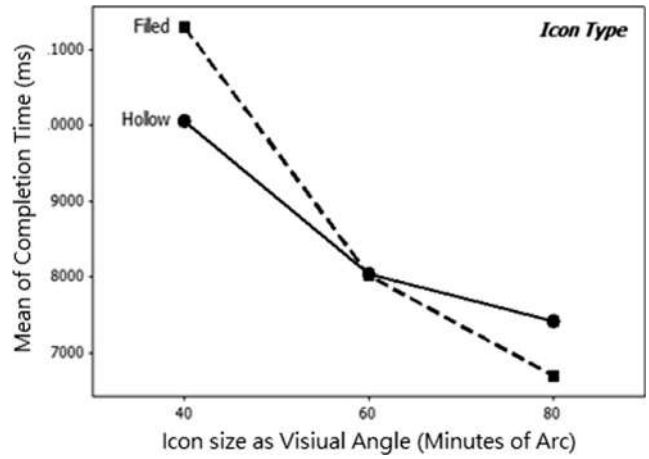

Fig. 4. Interaction plot of icon size and icon type for completion time.

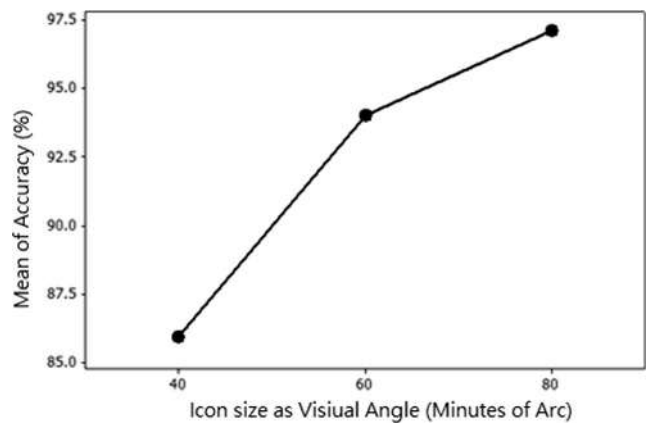

Fig. 5. The main effects plot of icon size for accuracy.

3.2. Accuracy

The ANOVA results showed a significant main effect of icon size on accuracy ($F = 10.37$, $p < 0.01$). The ANOVA results indicated a significant difference between map background clutter and icon size ($F = 5.98$, $p < 0.01$). However, the main effect of icon type and map background clutter was not significant. The interaction effects of icon type with map background clutter and icon size were also not significant. The significant main effect is presented graphically in Fig. 5,

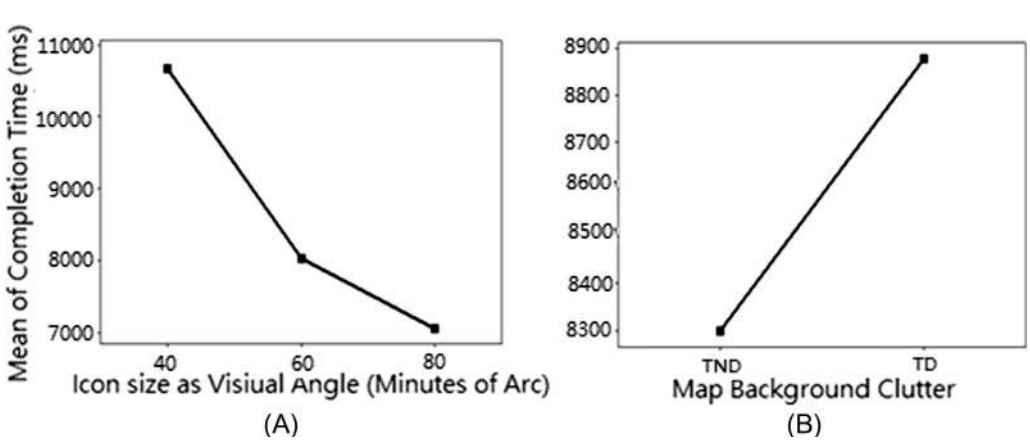

Fig. 3. Main effects plot of icon size (A) and map background clutter (B) for completion time.

and the interaction plot is shown in Fig. 6. The best level was the level that provided the highest value of accuracy. The experimental results indicated that icon size of 40 min was associated with lower accuracy and that of 80 min was associated with higher accuracy. Moreover, the results showed that small icon size greatly influenced the accuracy under a different map background type. The results indicated that small icons on TND background had higher accuracy compared with that on TD. However, medium icons had higher accuracy on TD background compared with that on TND background.

3.3. GSR

The ANOVA results indicated a significant main effect of map background clutter on GSR ($F = 22.20$, $p < 0.01$). They also indicated a significant interaction between icon type and map background clutter on GSR ($F = 5.44$, $p < 0.05$). However, the main and interaction effects for icon size and icon type were not found. The means are presented graphically in Fig. 7. Fig. 8 illustrates the detailed relationship between icon type and map background clutter. The results reflected in Figs. 7 and 8 indicate that TD interference was probably the prime cause of surveillance operators' cognitive pressure. Fig. 8 shows that cognitive pressure (GSR %) was more variable for the hollow icon than that for the filled icon type. The results illustrated that participants have good performance under the hollow icon on the TND map background. However, the situation was different for the TD map background. The hollow icons did not adapt well to the TD map background.

3.4. Pupil diameter

The results on pupil diameter indicated significant main effects of

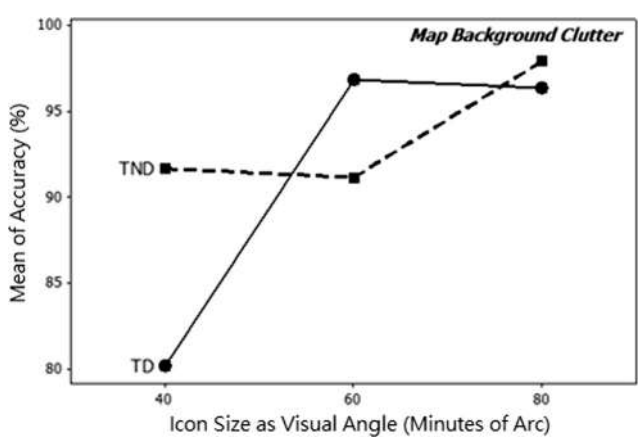

Fig. 6. Interaction plot of icon size and map background clutter for accuracy.

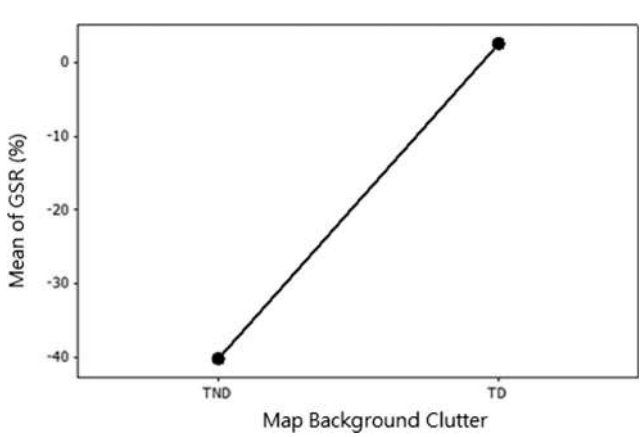

Fig. 7. Main effects plot of the map background clutter for GSR %.

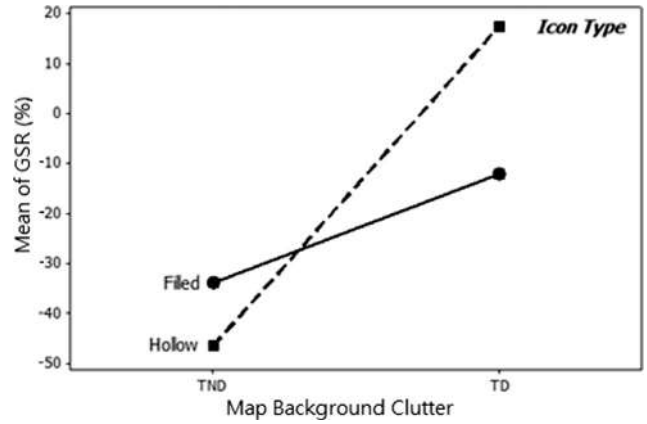

Fig. 8. Interaction plot of the map background clutter and icon type for GSR %.

icon size ($F = 7\ 4.93$, $p < 0.01$) and map background clutter ($F = 120.83$, $p < 0.01$). However, the main effect for icon type and the interaction effect between icon size and icon type, icon size and map background clutter, and icon type and map background clutter were not found. Fig. 9 presents the mean pupil diameter of participants using different levels of icon size and map background clutter. Fig. 9(A) provides a strong evidence that large icon size can effectively reduce cognitive pressure (mean small pupil diameter). Furthermore, the result of a two-map background clutter in Fig. 9(B) revealed that TD interference seemed to be the cause of the increasing participants cognitive pressure.

Many educational initiatives that emerge from this case study can be applied in ergonomics. The following discussion focuses on findings that relate to GIS design improvement and learning performance.

4. Discussion

We present the results of a case study on ergonomic interventions of GIS design. We begin our discussion by reviewing the findings of the GIS case study and the findings to the educational initiatives in ergonomics interface design. The main three findings of this study are summarized as follows:

(1) The participants were unanimous in support of the TND map background clutter. Different map background clutter conditions showed that TND interface had a shorter completion time and less cognitive pressure compared with the TD interface. These results may have emerged because the TND map background clutter was black, which may have increased the color contrast between the icon and the map background clutter. The TND target/map background clutter combination had high color differences. These results are partially consistent with those of previous studies [55–57]. However, this study proposed hypotheses of target/background clutter for GIS design. The new findings underscore the importance of recognizing the preference of GIS operators for high target/background difference. the participants do not like a cluttered background to interfere with their search, especially under emergent surveillance radar situation.

(2) The effect of icon size on completion time, accuracy, and cognitive pressure of pupil diameter showed that large icons resulted in shorter completion time, higher accuracy, and lower cognitive pressure compared with small icons. These results are also consistent with previous literature, which indicated that search time decreases when the icon size increases [55,58]. These results may be attributed to the optimum learning performance due to the combination of 80-min icon size and 21-inch screen. Such an explanation may account for the relative simplicity of the learners' request of a suitable target/display dimension ratio.

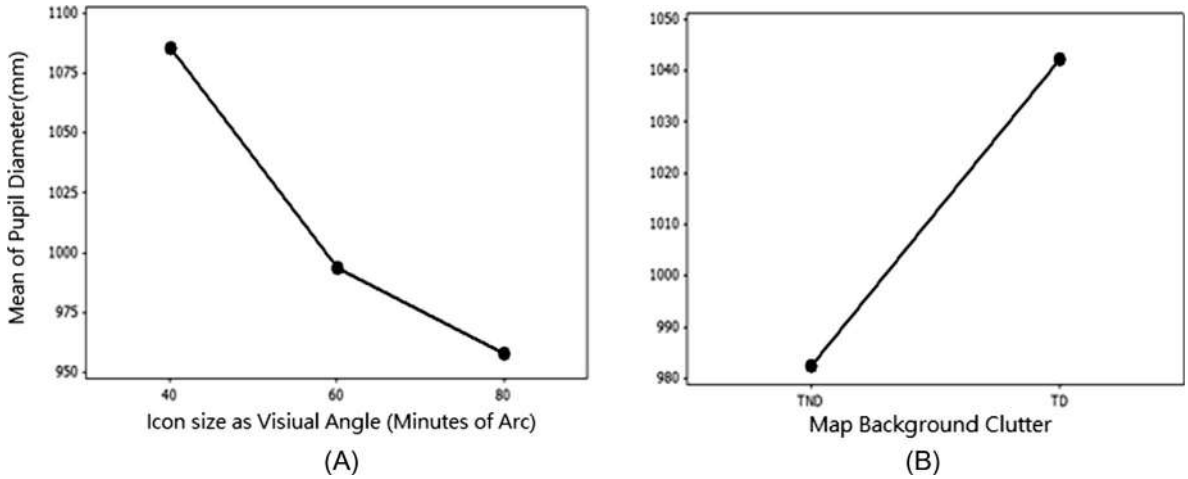

Fig. 9. Main effects plot of icon size (A) and map background clutter (B) for pupil diameter.

(3) Icon type targets demonstrated that the filled icons can be recognized faster compared with hollow targets when icons are large. However, the results for small versus large icon size conditions were contradictory. Moreover, the accuracy was lower for hollow rather than filled targets when icons are small. The hollow icons were more variable in terms of accuracy and cognitive pressure of GSR compared with filled icon types. The findings demonstrated that the adoption of a hollow icon type on the GIS interface must be treated with caution. The participants learned well when hollow icons were presented on the TND map background but were not suitable for the TD map background. However, the icon size and map background clutter interact with the use of icon type. These findings suggested the need to consider ergonomic concerns and design interventions to enhance the surveillance performance of operators using the GIS interface.

5. Conclusions

This case study showed encouraging results and proposed an improved interface design of the geographical intelligence system and effective educational initiatives in ergonomics. The four guidelines of designing this kind of systems are as follows. (1) Topography not displayed target/map background clutter combination has the advantage of high color differences. (2) The combination of 80-min icon size and 21-inch screen produced optimum learning performance. (3) Filled icons are easily recognized under a large icon size condition. (4) Hollow icons are not suitable for the topography displayed map background.

We investigated the relationship among three display parameters. However, we believe that further research is needed to develop a highly comprehensive guideline for a user interface design for methods that improve learning performance and strategy.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.displa.2017.11.001.

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