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Evaluating camouflage design using eye movement data

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ABSTRACT

This study investigates the characteristics of eye movements during a camouflaged target search task. Camouflaged targets were randomly presented on two natural landscapes. The performance of each camouflage design was assessed by target detection hit rate, detection time, number of fixations on display, first saccade amplitude to target, number of fixations on target, fixation duration on target, and subjective ratings of search task difficulty. The results showed that the camouflage patterns could significantly affect the eye-movement behavior, especially first saccade amplitude and fixation duration, and the findings could be used to increase the sensitivity of the camouflage assessment. We hypothesized that the assessment could be made with regard to the differences in detectability and discriminability of the camouflage patterns. These could explain less efficient search behavior in eye movements. Overall, data obtained from eye movements can be used to significantly enhance the interpretation of the effects of different camouflage design.

1. Introduction

Camouflage is an important part of the modern military. Camouflage is used to disrupt the contour of a target by merging it with the background, making it harder to detect or hit. Military camouflage must be used against different backgrounds and in different natural environments, including jungles, woodlands, and deserts (Hogervorst et al., 2010). Two visible trends dominate camouflage design today. One is universal design, and the other is specialized design, or using separate designs for desert environments. Clearly, a universal pattern will not perform better than a specialized pattern (Hogervorst et al., 2010). Traditionally, designs were inspired by natural environments and based on biological or psychological principles such as blending and disruption. More recently, the multiple disciplines of image stimuli processing, computer vision, statistics, human visual perception, and ergonomics have been integrated into the design considerations of camouflage (Scott-Samuel et al., 2011; Troscianko et al., 2009; Copeland and Trivedi, 2001; Toet et al., 1998).

The most challenging aspect of camouflage assessment of different camouflage patterns and battlefields is that it is hard to measure the effective acuity of the camouflage. Traditionally, subjective assessments, such as questionnaires, were used for testing, but such approaches lack the support of experimental data. Other subjective assessment methods have also been developed. Photosimulation, for example, presents a set of image slides of camouflaged targets against preferred backgrounds for participants to identify the performance of the designs visually and subjectively (Doll et al., 1993; Boyce and Pollatsek, 1992). Using simulations has the advantage of measuring performance under controlled conditions by bringing battlefield images to the participant, rather than bringing the participant to the battlefield. In fact, the research of the NATO Workshop SCI-012 noted that man-in-the-loop assessment was still the only robust and effective way to evaluate camouflage detectability (Toet, 2000; Doll and Home, 1999). Much of the previous visual search research attempted to use response time (RT) and error rate to evaluate camouflage effects on the human visual system. It was found that error rates or hit rates in the target-present (TP) data and in the target-absent (TA) data sometimes did not have sufficient sensitivity to reflect the performance of the human vision system (Neider et al., 2010; Neider and Zelinsky, 2006; Wolfe et al., 2002). In this paper, we focus on the fact that detailed information on human visual responses is needed for measuring camouflage performance.

One way to measure human visual responses is to use an eye tracker. The eye tracker has been applied in several fields to measure and record human eye movement information so that researchers can know where participants are looking at any given time and trace the eye movement from one position to another. The use of eye trackers in experiments was first pioneered in reading research over 40 years ago (Rayner, 1998). Technological advances

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have allowed the design of innovative eye movement experiments in which the visual tracker system is changed contingent on experimental demands, such as computational support in designing stimulus displacement conditions and organizing other bottom-up input in eye tracker systems (McConkie and Currie, 1996). General theories of language processing (Findlay, 2004; Liversedge and Findlay, 2000), attention (Kimble et al., 2010), and spatial ability (Alexander, 2006) were developed using eye tracker systems for critical examination of the cognitive processes underlying reading.

Although many studies of eye movement have focused on reading, relatively few studies have focused on visual searches (Rayner, 1998). For example, Boersema et al. (1989) presented tasks using pictorial stimuli for tracking eye movements. Najemnik and Geisler (2005) used an eye tracker to design experiments to determine optimal eye movement strategies. Zelinsky (1996) recorded eye saccades to assess the selectivity of search movements. In the military field, Hauland (2003) investigated situational awareness in air-traffic-control training, and that research was helpful in evaluating the design of cockpit controls to reduce pilot error (Casner, 2009; Hanson, 2004). Eye trackers have also been used to investigate threatening stimuli in veterans of war (Kimble et al., 2010). From the above studies, it was found that the nature of a search task affects the behavior of eye movement, and that every statement about visual search or eye movements must be qualified by the characteristics of the search experiment. The most important findings were that these measurements included not only traditional psychophysical factors, such as response times and error rates, but also more detailed data, such as eye-movement trajectories. Analyzing the search strategy or procedure is helpful because visual information that shares certain characteristics with target items often attracts a disproportionately large number of fixations or saccades (Di Stasi et al., 2011; Duchowski, 2003; Rao et al., 2002).

Several eye movement variables have been used in past visual search investigations. Goldberg and Kotval (1999) employed the following: (1) Number of Fixations: The number of fixations is related to the number of components that the user is required to process. When searching for a single target, a large number of fixations indicates that the participant sampled many other objects prior to selecting the target, as in cases where something hindered attention or distracted the participant from isolating the target. For example, in the study by Goldberg and Kotval, a poor interface, intentionally designed to mislead the subject, produced significantly more fixations than a good design. In short, a higher overall number of fixations indicates a less efficient search. (2) Fixation Duration: Also in a study by Goldberg and Kotval (1999), a longer fixation implied the participant was spending more time interpreting or relating the component representations in the interface to internalized representations. A longer duration of fixation can indicate difficulty in extracting information, but it can also mean that the object is more engaging in some way (Scialfa and Joffe, 1998; Just and Carpenter, 1976). (3) Saccade Amplitude: In a study of computer display interface design, Goldberg found that larger saccadic amplitudes and fewer interim fixations indicated that users scanned to desired targets more effectively. Another useful indicator is the first saccade amplitude to region of interest. A larger saccade amplitude indicates that the user's attention is drawn from a distance to the target (Goldberg et al., 2002) or an anticipatory response is initiated with a saccade (Cirilli et al., 2011). Besides these factors, other factors have also been discussed in the literature. Maximum and average fixation times are context-independent measures, but the duration of single fixations on targets is dependent on the layout of the stimulus target. Thus, the number of fixations per region of interest has also been used. For example, a high number of fixations on a particular region indicates that it is more noticeable, or more important, to the viewer than other regions (Poole et al., 2004). Blink rate can be used as an index of cognitive workload. A higher blink rate may indicate fatigue (Yagi et al., 2009; Bruneau et al., 2002). Although much research has focused on attractive targets, little research has studied the detection of unattractive targets by the visual system. In the field of military camouflage design, traditional psychophysical factors such as detection time and hit rates are used to assess the performance of camouflage. Past research on target attraction showed that when distracters are similar to targets (Neider and Zelinsky, 2006), it is insufficient to analyze only increases in fixation time, and one should not ignore other characteristics that influence the result. Fixations, saccades, or other information on eye movement can allow researchers to identify such characteristics (Havermann et al., 2012; Unema et al., 2005; Phillips, 1981; Noyes, 1980). In this study, we applied a camouflage target detection experiment to assess different kinds of camouflage on different battlefields, using an eye tracker. In this paper, all the results are analyzed, and those factors that provide better assessment of camouflage performance are identified.

2. Methods

2.1. Participants

Fifteen male student participants from the National Defense University took part in the study. Participants ranged in age from 19 to 23 years old. All participants had more than one year of military training and education. All participants had normal or corrected to normal vision (e.g., normal performance on the Landolt C vision test). None of the participants suffered vision-related illnesses or color-blindness.

2.2. Apparatus

Eye movements were sampled using an Eyelink II eye tracking system (SR Research, Osgoode, Ontario, Canada). This system uses a head-mounted camera to track the pupil image and corneal reflection, with a sampling rate of 500 Hz and spatial accuracy of 0.5° or higher. Three cameras mounted on the Eyelink II headband allowed simultaneous tracking of eye and head positions, such that gazing positions were computed with head motion unrestrained. A personal computer (Intel Core i5-750 2.66 GHz), connected to a remote Ethernet link, was used to respond to the displayed stimulus and to trigger the eye tracker in each trial.

Stimuli were shown on a 24.1-inch LED (EIZO color edge 243W) industrial color correction monitor with a resolution of 1920×1200 pixels. The participant placed his head in a chin-rest to minimize head movements and viewed a screen placed 55 cm from the corneal surface, with dim background lighting. The display screen provided an optical image subtending 54° horizontally and 33.75° vertically.

The Experiment Builder (SR Research, Osgoode, Ontario, Canada) was used to design the experiment procedure, and eye movement data captured by the EyeLink II, mouse clicks, and keystrokes were recorded upon confirmation of stimuli on the computer screen. Fig. 1 illustrates the setup of the experiment. In addition, DataViewer (a professional eye movement analysis program) was used to arrange the data, mark the environment, and collect various index data for the built-in visualization module. DataViewer displayed the number of times the stimulus was detected, as well as the fixation points, saccade amplitude, and blinks.