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Sensitivity and Bias in Searches of Cockpit Display of Traffic Information Utilizing Highlighting/Lowlighting

Walter W. Johnson, Kevin Jordan, Min-Ju Liao, and Stacy Granada
Ames Research Center, Moffett Field, California

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Walter W. Johnson
Ames Research Center, Moffett Field, California

Kevin Jordan, Min-Ju Liao, and Stacy Granada
San Jose State University, San Jose, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

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Summary

A previous investigation showed that when bright and dim traffic symbols were mixed together on a cockpit display of traffic information, dim targets required longer search times than bright targets. The current experiment utilized Signal Detection methodology to determine the cause of this effect. Two factors were manipulated, Intensity and Mixture. The Intensity manipulation varied whether targets were bright or dim. The Mixture manipulation varied whether the brightness of all aircraft symbols was the same, or if half were bright and half dim. Participants were given 1.25 s to search a display of eight aircraft and determine whether a target was present or absent (50% of the time a target was present) and then rated their confidence in the accuracy of their decision. A Mixture by Intensity repeated-measures ANOVA on the signal detectability measure, A' (a non-parametric variant of d'), revealed that targets presented at the dim intensity in the mixed condition yielded significantly lower sensitivity than either of the pure (homogenous) conditions or the bright targets in the mixed condition. There was not a significant difference in False Alarm rates between any conditions, indicating no change in decision criterion. Findings are discussed in terms of possible masking effects evoked by bright aircraft over the dim aircraft. Funding for this work was provided by the Advanced Air Transportation Technologies Project of NASA's Airspace Operation Systems Program.

Introduction

An ideal Cockpit Display of Traffic Information (CDTI) depicts sufficient information to provide the pilot with situation awareness while minimizing attentional demands and search time. One possible method to achieve this goal is to use visual features to segregate information on a display into more and less important items, and to subsequently direct pilots' attention. Brightness highlighting is one such feature, and it is believed that this display feature will enhance visual search performance within an informationally-dense CDTI.

The effects of highlighting in directing users' attention and enhancing their performance in a visual search task have been previously examined in theoretical and applied settings. At the theoretical level, research has shown that salient items may be involuntarily processed first in visual search tasks, indicating that "bottom-up" processing is important in the deployment of attention (e.g., Joseph & Optican, 1996; Kawahara & Toshima, 1997). By way of example, Pashler (1988) showed that when color was irrelevant in a visual search task, participants still took longer to locate a target when distractor color singletons appeared. Similarly, Theeuwes (1991a, 1992) found that irrelevant singletons could attract participants' attention during visual tasks. However, highlighting is not always beneficial. Fisher and Tan (1989) found that the level of highlighting validity, and the probability that users attend first to the highlighted options (i.e., top-down processes) both determine whether highlighting benefits performance. In fact, they showed that highlighting sometimes worsens performance when the form of highlighting tends to mask the identity of the highlighted item. They termed this negative effect a "highlighting paradox".

In our previous work evaluating the effects of highlighting on visual search performance on a CDTI (Johnson, Liao, and Granada, 2002), the evidence for a bottom-up influence of stimulus intensity (brightness) was, in fact, unclear. In this study participants were required to detect a target aircraft (a target was always present) from among a mixed set of bright and dim aircraft, or a pure (homogenous) set of all bright or all dim aircraft. The detection of dim targets in the mixed condition was inhibited compared to detection of dim targets in the pure dim condition, while bright targets were detected equally fast in the mixed and pure bright conditions. Johnson et al posited that the bright targets might have masked the dim targets through a form of contrast inhibition.

These results were similar to those found by Kroft and Wickens (2001), who reported that processing of information from lowlighted parts of a display was negatively impacted, while processing of highlighted information was not affected for good or ill. Kroft and Wickens also hypothesized that this may have been the result of the bright-dim contrast reducing the readability of the lowlighted information.

Signal detection theory provides a framework for further exploring the observer's differential responses to dim and bright highlighting. In particular, signal detection theory breaks down the process of classifying observations as targets (signals) or non-targets (noise) into two elements. The first element corresponds to <u>sensitivity</u>, which is driven by signal strength. During the time-course of an observation, evidence of a signal (target) mounts faster for a stronger signal than for a weaker signal, while noise causes it to randomly increase and decrease for a non-signal (non-target). The second element corresponds to the decision-rule, or <u>criterion</u>, which is used to decide whether there is enough evidence to classify an observation as a signal (target) or non-signal (non-target). A liberal criterion leads an observer to respond 'signal,' or 'target present,' on the basis of less evidence, thus leading to both a higher hit rate and to more false detections. The opposite is true for a conservative criterion.

The present study sought to extend the examination of dim/bright highlighting on a CDTI by applying a signal detection framework to a task more like one that could be expected on a flight deck. The type of search that we previously studied, effectively gave the observer unlimited time to inspect the alternatives. Since, in this case, a very conservative decision criterion could be set, very little error was expected or found. A

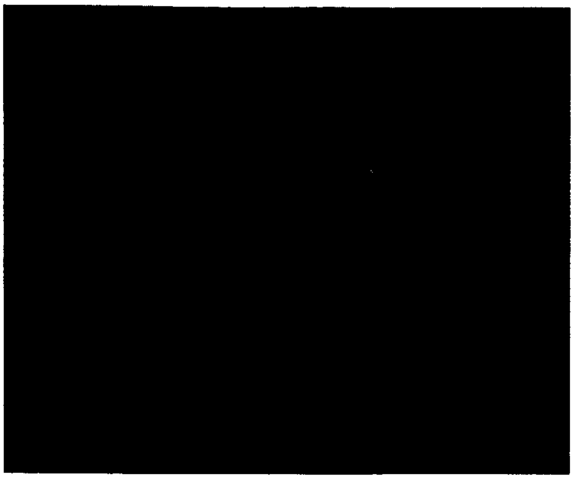

Figure 1. Illustration of CDTI display of mixed bright and dim traffic aircraft.

second type of search, studied less often, is speeded search, where the observer is only given a short amount of time to inspect the alternatives. This approach more closely approximates the activity of a pilot monitoring a CDTI. Since the CDTI is just one of many flight deck displays which must be scanned, the inspection of the CDTI must be brief.

If, as proposed by Johnson et al (2002), observers are equally sensitive to bright and dim targets when they are presented in homogenous displays (all bright or all dim), and only differentially sensitive to bright and dim targets when they are in mixed displays, then this should be reflected in the sensitivity parameter of signal detection theory should be lower for detections of the dim targets in the mixed-sets than for detections of the targets in the other three conditions.

Johnson et al further concluded that brighter targets did not differentially attract attention. They based this on the fact that there was no statistically significant difference between the times to detect bright targets in the mixed sets, and the bright and dim targets in the pure sets. Thus, there was only a negative effect on the detection of dim targets.

However, it is possible that such an effect of attention could be masked by the presence of a shifting decision criterion. That is, if brightness in the mixed sets actually attracted attention, but was accompanied by an increase in the decision criterion (a conservative bias), these effects could cancel each other out. The decision criterion shift would extend the search times for both dim and bright targets in the mixed sets, and the role of brightness in attracting attention would be underestimated. If this were true, it would also be reflected in a signal detectability analysis as a change in the criterion parameter.

The goal of the current study was to determine the role of sensitivity and decision-rules in the detection of dim and bright targets in mixed and pure sets of bright and dim aircraft on a CDTI. A signal detection methodology, which provides independent measures of perceptual sensitivity and the decision criterion, was employed in the present study to answer this question.

Method

Stimuli and Design

In the present experiment, a CDTI presented one Ownship symbol (participants' aircraft) located at the bottom of the display, and eight other aircraft symbols pseudo-randomly placed throughout the display, with the constraint that there would always be two aircraft within each of the four quadrants of the display (see Figure 1). The target aircraft was defined as one traveling on a colliding path with Ownship. On half of the trials a target aircraft was present, while on the other half there was no target. Among the target-present trials, the target appeared equally often in each of the four regions of the display to minimize possible location effects. All aircraft on the display were noted as maintaining the same altitude and speed as Ownship. Furthermore, each of the distractor (non-target) aircraft maintained placements and headings designed to miss Ownship by a visually wide margin; thus, it was obvious whether or not any particular aircraft symbol was the target, and subjects did not have to compare alternatives to find the best choice.

For the target-present trials two within-subjects factors, Mixture and Intensity, were manipulated. For 50% of the trials the target Intensity was Bright, while for the other 50% the target Intensity was Dim. Likewise, for the trials within each of these two conditions, 50% of the time the target and distractors had the same Intensity (Pure presentation), and 50% of the time the target and three distractors had the same intensity, while the other four distractors had the other intensity (Mixed presentation).

For the target-absent trials it was not possible to manipulate target Intensity. Therefore, 50% of the trials used a Mixed presentation (matching the 50% of target-present trials with a Mixed presentation), while 25% of the trials used a Pure presentation with Bright symbols, and 25% of the trials used a Pure presentation with Dim aircraft (again matching the 25% of the target-present trials with Pure Bright and with Pure Dim presentations).

The luminances (intensities) of the bright and dim aircraft were 1.81 cd/m^2 and 0.28 cd/m^2, respectively, against a black background of 0.0014 cd/m^2. Ownship intensity was always presented at a level between the bright and dim aircraft, and was a solid rather than outline form.

Participants

Sixteen people working at NASA Ames Research Center (3 females, 13 males) volunteered for the experiment. All participants had normal or corrected-to-normal vision and were naïve as to the purpose of the study.

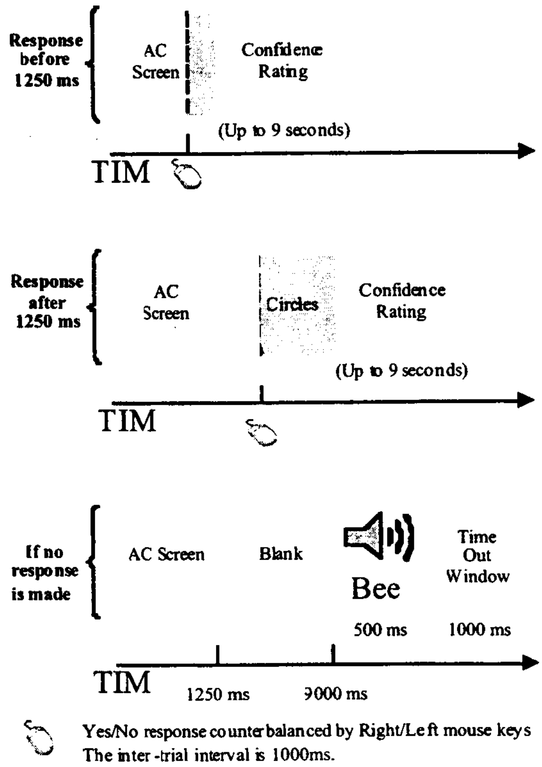

Figure 2. Time-course followed during each trial.

Apparatus

The current experiment utilized an Intergraph Pentium 200 system with a 20-inch (51 cm) diagonal SVGA (1024 x 1280) monitor. The vertical and horizontal dimensions of the CDTI measured approximately 25 cm each, and the viewing distance was approximately 48 cm. This resulted in a visual angle of 29 visual degrees for both dimensions. The display updated 60 times per second.

Procedure

All participants listened to a detailed account of the experimental procedures, then read through similar instructions before proceeding to the practice and experimental sessions. The participants' task was to make, as quickly as possible, "yes /no" judgments about the presence of a target aircraft. After responding "yes" or "no", participants were further required to rate their confidence that their responses were correct on a scale from one (least confident) to five (very confident). Half of the participants used the left mouse button to indicate a "yes" response and the right mouse button to indicate a "no" response, while the other half had these response buttons switched.

On each experimental trial the CDTI aircraft symbols were presented for 1.25 seconds. At this point they were replaced by non-directional circles, which then remained until participants responded, or until a timeout at nine seconds. This circle served as a mask to eliminate any lingering sensory representation of the aircraft symbol. Subsequently, participants had nine seconds to rate their confidence. If the response to the threat detection or the confidence rating was not made within the allotted time, that trial timed out and a new trial automatically started (see Figure 2 for an illustration of the procedure). During the practice trials, participants had five seconds to view the aircraft, and the experimenter was present to interact with them and ensure they understood the task.

After all participants completed 24 practice trials, they received three blocks of trials, one with all bright traffic symbols, one with all dim traffic symbols, and one which presented a mixed set (4 bright and 4 dim). There were 2.5-minute breaks between each block. The order of these three blocks was counterbalanced across participants with the constraint that the two pure blocks were always presented in succession. There were 128 trials in each block, with 64 target-present trials and 64 target-absent trials. In the Mixed condition, the 64 target-present trials included 32 bright and 32 dim targets.

Results

The initial analyses focused on determining the receiver operating characteristic (ROC)

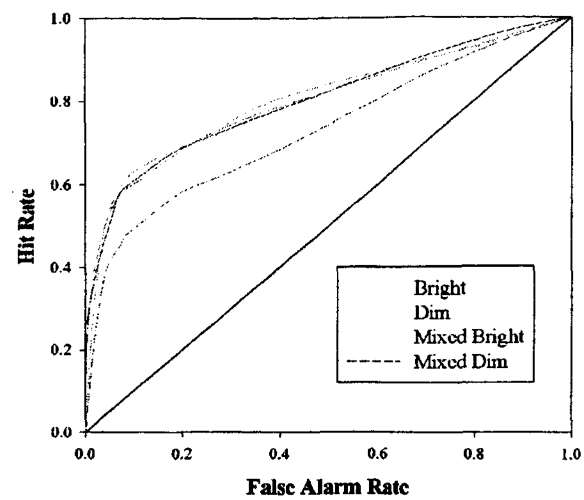

Figure 3. Mean receiver operating characteristic (ROC) curves as a function of Intensity and Mixture.

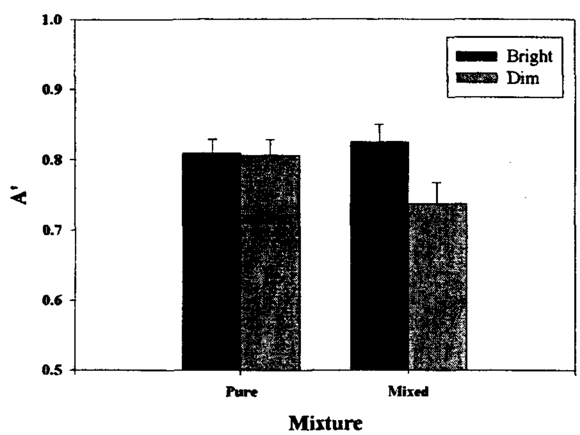

Figure 4. A´ as a function of Intensity and Mixture.

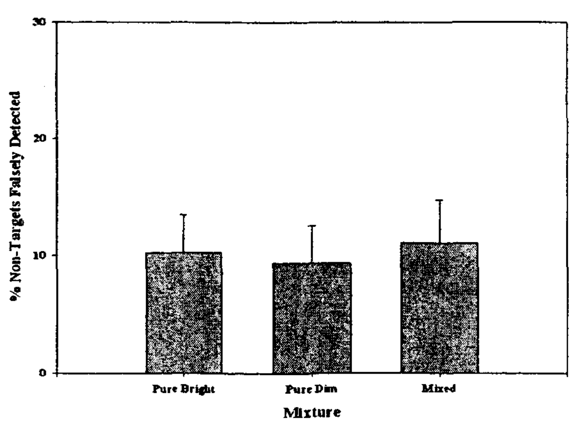

Figure 5. False-alarm rates for conditions not target-absent containing.

curves for the four conditions corresponding to bright and dim target Intensities for the pure and mixed Mixture conditions. These were obtained using the confidence measure and the analysis procedure outlined in Macmillan and Creelman (1991). Figure 3 shows this effect, with a clearly different ROC for the dim intensity-mixed presentation condition, and virtually identical ROCs for the other three conditions. Also, note that the individual and mean ROC curves were not symmetric about the negative diagonal. This demonstrated a violation of the assumption of normal and equal variance noise and signal-plus-noise. Therefore the nonparametric signal detectability measure, A´, a measure of the area under the ROC curve, was used instead of the parametric d´ measure.

Figure 4 shows the mean A´ values as a function of Intensity and Mixture. A 2 x 2 fully within-subjects ANOVA revealed a significant main effect of Intensity (F (1, 15) = 13.06, p < .01) and a significant Intensity x Mixture interaction (F (1, 15) = 10.27, p < .01). Follow-up analyses showed these effects were due to lower A´ values for the dim intensity targets in the mixed condition, while the A´ values for the other three conditions were not found to differ among themselves.

Due to the non-symmetrical ROCs, examination of the effects of shifts in the relative likelihood response bias parameter, β, was also deemed inappropriate. However, a simple examination of the false-alarm rate was sufficient to show that no shift in the detection criterion had occurred. That is, assuming that noise distributions do not vary across conditions, false-alarm rates should vary if there is a change in the amount of evidence deemed necessary to conclude that a target is present. Such a shift should change the number of times a person falsely concludes that a target is present. Figure 5 shows that the mean frequency of false target detections in the three no-target conditions (false alarms) did not change significantly (F (1,15)=0.269, p = .612). Thus there is no evidence of a change in the decision rule.

Given the lack of change in false-alarm rate, it follows that analyses of variance performed on overall accuracy (% correct overall) and hit rates (% correct in the target present conditions) should show the same pattern of effects found for the A' analysis. This was the case and therefore they are not reported here.

Discussion

The current results parallel the results from our previous study (Johnson et al., 2002). Both studies showed that mixing bright and dim alternatives in a search task neither aids nor hinders detection of bright targets (as compared with the detection of targets in unmixed, or pure, presentations). On the other hand, both studies also showed that the mixture of bright and dim alternatives hinders the detection of dim targets. The two studies used different methods to show this effect. Johnson et al (2002) measured the amount of time it took to find the target, and found delayed detections of the dim targets in the mixed condition. The present study limited the amount of time given to the participant to determine if a target was present, and found decreased accuracy for the detection of the dim targets in the mixed condition. Both studies found equivalent performance when participants had to search for dim or bright targets in unmixed conditions, and that this was, in turn, equivalent to performance on the bright targets in the mixed conditions.

In addition to providing a converging operation in support of the Johnson et al (2002) findings, the present study also confirmed that the effects are solely due to differential sensitivity, and not to shifts in decision criteria. That is, the sensitivity to bright targets in the mixed condition, as compared to targets in the pure, or unmixed, conditions, was equivalent with decision processes partialled out. In fact, there were no shifts in decision criteria.

This pattern is most easily explained by lateral inhibition. The inhibitory effect of the dim stimulus on the bright stimulus is negligible, while the bright stimulus exerts a much stronger inhibitory effect on the dim (Hartline, 1949). The implication of this asymmetric effect for the design of cockpit displays of traffic information is to caution against relying on brightness contrast for highlighting purposes when the dim alternatives remain potentially relevant. That is, if brightness is not highly correlated with what should be attended first, then the decreased sensitivity to the dim alternatives may outweigh any gains from having the bright stimuli examined first.

Finally, the task in this study more closely matched how a pilot might be expected to scan a CDTI, than did our previous study. That is, this study used a task that required a quick time-limited examination, similar to a pilot's scan of his or her instruments. So this study showed that the cost of a design involving mixed bright and dim alternatives may not be just a small bump in the time needed to extract information (on the order of 150-200 ms in the study by Johnson et al, 2002), but actually missing the relevant information.

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