EasyChair Preprint

№ 5424

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May Jorella Lazaro, Sungho Kim and Myung Hwan Yun

April 29, 2021

Extended Abstract from 21st Triennial Congress of the International Ergonomics Association, Vancouver, June 13 – 18, 2021

Guided Target Detection in Cockpit Displays: A Bayesian Modeling Approach

May Jorella S. Lazaro[a], Sungho Kim[a], Myung Hwan Yun[a]
a – Seoul National University, South Korea
ellalazaro@snu.ac.kr

SUMMATIVE STATEMENT
The effects of conjunction features to the target detection performance in cockpit displays were analyzed by employing the hierarchical signal detection model. The present study gave insights on how different search conditions leads to changes in the underlying psychophysical processes (detection sensitivity and response bias) during guided search tasks.

KEYWORDS: Hierarchical Signal Detection Model, Bayesian Analysis

PROBLEM STATEMENT
Current air force flight systems are continuously being developed to increase the level of flight automation. With this, cockpit displays are becoming more loaded with multiple information regarding the aircraft state leading to the rise of complex interface designs. This increase in display intricacy, characterized by combinations of visual features, can negatively influence pilots' performance and work efficiency. This could lead to critical situations, especially in searching for targets during aerial warfare. During target search and detection, visual features that differentiate the target from non-targets plays an important role in increasing detection sensitivity. Research has found that increased number of common features shared by both the target and non-targets are detrimental to search performance (Eckstein et al., 2000). However, current cockpit displays are designed to integrate as much information possible through incorporating various visual features (Kim et al., 2011). Thus, to ensure the effectiveness of such display systems, investigating the effects of discriminatory visual features to a person's target detection performance is essential.

RESEARCH OBJECTIVE/QUESTION
The present study aims to compare target detection performance and to uncover the basic psychophysical processes underlying the guided detection of targets in aircraft cockpit displays across different search conditions through Bayesian analysis.

METHODOLOGY
Seventeen participants (13 males, 4 females) with a mean age of 25 (± 2.40) were recruited for the experiment. Each participant completed 120 trials of a guided target detection task following a yes/no design across different search conditions. The three conditions were feature search, conjunction search and triple conjunction search. In feature search condition, the target differs from the non-targets by a unique visual feature. Whereas, in conjunction search (triple-conjunction search), the target differs from the non-targets by a combination of two (three) visual features. For every experimental trial, the participants were asked to decide whether the target is present or not in a cockpit display by pressing a button that corresponds to their choice. After the session, the participants were asked to subjectively evaluate the level of difficulty (LOD) for each condition. With the use of Markov chain Monte Carlo (MCMC) sampling, a hierarchical Bayesian signal detection model was utilized to model the target detection performance of the participants across the three search conditions. The resulting parameter values for response bias, detection sensitivity, hit rate and false-alarm rate was compared across different conditions through repeated-measures

ANOVA with Bonferroni corrections. Lastly, pairwise t-test was conducted for post-hoc analysis.

RESULTS

All chains of each condition and parameters were found to be at convergence after 4000 iterations (discarding 1000 burn-in samples) using $\hat{R}$ (all $\hat{R} < 1.1$). Results of the repeated-measures ANOVA of the estimated parameter values revealed the main effects of search condition in response bias ($F(2, 32) = 52.48$, $p < .001$), detection sensitivity ($F(2, 32) = 22.82$, $p < .001$), hit rate ($F(2, 32) = 11.65$, $p = .003$), and false alarm rate ($F(2, 32) = 9.64$, $p = .004$). The response bias was significantly higher in the triple conjunction search condition (0.22 ± 0.12) than conjunction search (0.13 ± 0.04) and feature search (0.03 ± 0.09) conditions. On the other hand, detection sensitivity was significantly lower in triple conjunction search condition (3.64 ± 0.72) than in conjunction search (4.07 ± 0.29) and feature search (4.55 ± 0.18) conditions. In terms of hit rate (false alarm rate), although feature search (0.98 ± 0.01/0.02) and conjunction search (0.96 ± 0.01/0.02 ± 0.01) conditions did not show any significant difference after the post-hoc analysis, it was revealed that in the triple conjunction search condition (0.92 ± 0.07/0.03 ± 0.02) the hit rate was significantly lower (higher) than both conditions. Lastly, the results of the subjective measure revealed that the perceived LOD was higher for the triple conjunction search followed by conjunction and feature search conditions.

DISCUSSION

The results suggest that conjunction search reduces detection sensitivity during a guided target detection task. This effect is also evident in the significant drop (rise) in hit-rate (false-alarm rate) during triple-conjunction search. This implies that an increased number of common features shared by the target and non-targets leads to the heightened difficulty in stimuli discrimination, which in turn impedes target detection performance. Results from the subjective measure also support this notion whereby the increase in the perceived LOD is proportionate to the increase in the number of conjunction features. Furthermore, it was revealed that the participants are more conservative in deciding whether the target is present when there are more conjunction features.

CONCLUSIONS

The findings of the present study provided initial accounts with regards to the underlying psychophysical processes (detection sensitivity and response bias) during guided target detection in cockpit displays. It was revealed that multiple conjunction features increase the difficulty of target detection, which then leads to higher conservativeness. Thus, cockpit displays should consider reducing conjunctive visual features for critical target detection tasks that require higher sensitivity.

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