Insights from Eye Movement into Dynamic Decision-Making Research and Usability Testing

Benoit R. Vallières, Cindy Chamberland, François Vachon, and Sébastien Tremblay

Co-DOT Laboratory, School of Psychology, Université Laval, Québec, Canada
benoit.roberge-vallieres.1@ulaval.ca,
{cindy.chamberland,francois.vachon,
sebastien.tremblay}@psy.ulaval.ca

Abstract. This study shows how the use of various measures of eye movement can serve to portray dynamic decision-making (DDM) in a coherent fashion. We extracted eye movement metrics relative to 1) scanpath, 2) eye fixations, and 3) pupillary response, to characterize DDM during the process of risk assessment. Results from Experiment 1 revealed that incorrect classifications were associated with 1) less efficient information search, 2) difficulties in making sense of critical information, and 3) a low level of cognitive load. In Experiment 2, we used eye tracking to assess the impact on DDM of introducing a decision support system. The addition of a temporal-overview display seems to affect processing time in DDM as indexed by shorter scanpaths and fixations during classifications. These findings illustrate how event-based eye movement measures can reveal characteristics and limitations of the ongoing cognitive processing involved in DDM and also contribute to usability testing.

Keywords: Eye movements, dynamic decision-making, usability testing, decision support system.

1 Introduction

Dynamic decision making (DDM) involves a series of interdependent real-time decisions and actions made in an environment that continuously changes, and evolves according or not to operators' actions [1]. Air traffic control and military operations are examples of complex dynamic situations in which DDM is difficult to the point that it often taxes operators' cognitive capabilities [2]. In such situations, decision makers have to process and categorize information coming from multiple sources within a limited time frame [3].

The demands to support DDM are growing rapidly, but providing such support requires a good understanding of the underlying cognitive processes involved in DDM. One avenue that we wish to explore is to reveal these cognitive processes through the use of eye tracking in a manner that is closely linked to the dynamics of the situation [4-5]. Indeed, eye movements can provide non-obtrusive, online indices

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of cognitive functioning [6]. There are various ways in which eye movements can be measured to study a wide range of cognitive processes. Poole and Ball [5] highlighted different categories of eye movement metrics, each reflecting the action of specific cognitive processes. *Scanpath metrics* relate to saccade-fixation-saccade sequences of eye movements and can be used to index the efficacy in information seeking [5]. *Fixation metrics* measure how long the gaze is relatively stationary and can serve as estimates of processing (or encoding) time during DDM [6-7]. *Pupilometry* measures variations in the pupil diameter during DDM and can index the level of cognitive load [8].

In DDM studies, such metrics are usually exploited in isolation and are rarely used to investigate how a decision support system can affect information intake during DDM. The purpose of the present study was twofold. The first experiment aimed at demonstrating how the combination of different types of eye movement measures during the information intake can contribute to pinpoint the sources of errors in the context of a simulation of radar-based risk assessment. The goal of the second experiment was to test the potential of such an event-based eye-tracking approach to usability testing by assessing the impact of introducing a decision support system (DSS) on cognitive processes engaged in DDM.

2 Experiment 1

2.1 Method

Twenty-one adults reporting normal or corrected-to-normal vision and normal hearing took part in the experiment. We employed the S-CCS microworld (Figure 1), a low-level computer-controlled simulation of a naval anti-warfare [see 8-9] in which participants play the role of a tactical coordinator onboard of a frigate by conducting threat evaluation and weapon assignment. The simulation dynamically evolves according to a pre-determined scenario and takes into account participants' actions.

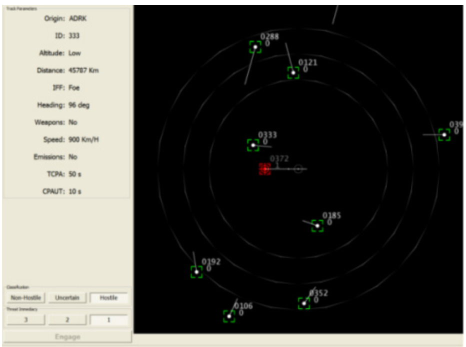

Fig. 1. The S-CCS display in Experiment 1

Participants performed three subtasks: threat-level and -immediacy evaluation and neutralization of hostile aircraft. Our analyses focused on the threat-level assessment subtask. In this task, participants had to categorize all aircraft moving on the radar according to a classification rule. This rule took into account 5 out of 11 parameters appearing in the list. Aircraft could be non-hostile, uncertain or hostile, and participants clicked on the classification buttons to record their decision. For hostile aircraft, participants must also judge threat immediacy and engage weapons.

The experimental session started with a tutorial explaining the context of the simulation, the mission and the task to perform, followed by a practice phase with static screenshots. Then, participants familiarized themselves with the S-CCS dynamic environment through eight training scenarios. The session ended with 16 4-min test scenarios, each including a set of 27 aircraft varying in speed and trajectory on the radar.

2.2 Results and Discussion

Eye movement measures were extracted from over 10,000 classifications (mean accuracy: 85.9%) and were classify as correct or incorrect decisions. Table 1 describes the eye-tracking metrics used in the present study with their meaning.

Table 1. Description of the eye movement metrics extracted during each classification

Type of metric	Metric	Description	Meaning
Scanpath	Scanpath duration	Mean duration (in ms) of the scanpath	Longer-lasting scanpath = Less efficient searching
	Scanpath length	Mean number of fixations in the scanpath	Longer scanpath = Less efficient searching
	Spatial density	Mean % of areas looked at to perform a classification	Higher density = Less efficient searching
Fixation	Mean fixation duration	Mean duration of a single fixation on relevant areas	Longer duration = Difficulty in extracting information
	Total fixation duration	Time spent fixating relevant areas	
Pupil response	% of change in pupil size	Pupil dilation when looking at relevant areas compared to a “baseline” dilation level	Larger pupil dilation = Increased cognitive load

Table 2. Eye movement metrics' mean obtained for correct and incorrect classifications

Metrics	Control (Exp. 1)		With TOD (Exp. 2)	
	Incorrect	Correct	Incorrect	Correct
Scanpath	●	●	●	●
Length	8.78	8.27	8.11	7.55
Duration (ms)	3077.41	2879.29	3282.35	3042.12
Spatial density	48.1	46.7	38.5	37.1
Fixation	●	●	●	●
Mean duration (ms)	246.72	233.38	187.91	183.5
Total duration (ms)	967.47	855.85	680.74	617.84
Pupillometry	●	●	●	●
% of change	-1.12	-0.27	-0.66	-0.62

Table 2 presents the results obtained for all metrics according to classification accuracy. Dependent-samples *t* tests performed on participants' means revealed a significant difference between correct and incorrect classifications for each metric. These results suggest that in the context of radar-based risk assessment, DDM errors were associated with impoverished efficacy to search for relevant information, difficulties in making sense of critical information, and transient slackening in the overall level of cognitive effort. This study illustrates how eye movements can be used to discriminate between correct and incorrect decisions in dynamic environments and, hence, provide insights into potential solutions (e.g., DSS, training) to improve the various aspects of cognitive functioning involved in DDM.

3 Experiment 2

The objective of Experiment 2 was to show how eye movement analyses can serve usability testing by examining the impact on threat evaluation of adding a DSS designed to support priorization and scheduling activities. A temporal overview display (TOD) was integrated to the original S-CCS interface (Figure 2) to support threat-immediacy assessment and defensive-measures management. While this tool was shown to promote temporal awareness for executing these subtasks [9], the holistic evaluation of its impact on other subtasks using eye-tracking is recommended.

3.1 Method

Twenty-two new adults participated to the experiment. Added to the right of the radar, the TOD represents temporal components such as time-to-decide and time to hit a target by presenting each aircraft (represented by a rectangle) across a timeline. An aircraft hits the ship when the right end of its rectangle crosses the red line.

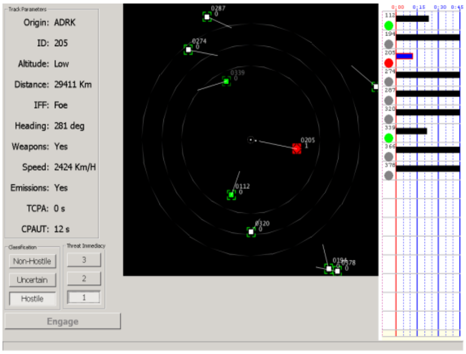

Fig. 2. The S-CCS display with the TOD located to the right of the radar screen

3.2 Results and Discussion

As shown in Table 2, the comparison of correct and incorrect classifications yielded the same results as in Experiment 1. When contrasting eye movement metrics between the two studies, independent-samples *t* tests revealed significantly lower spatial density and shorter fixations in the presence of the TOD. Such results suggest that promoting temporal awareness through the TOD influenced temporal aspects of the classification subtask as participants took less time to gather relevant information necessary to assess threat level. This experiment illustrates the potential of eye movements in uncovering the consequences of adding DSSs on cognitive functioning.

4 Conclusion

The present study was successful in showing that eye movements can be used not only to discriminate between correct and incorrect decisions in dynamic environments, but also to assess the impact of adding a DSS on different aspects of cognitive functioning, such as search efficiency. Taken together, our findings testified that dynamic, event-based measures of eye movement provide a window onto the ongoing cognitive processing in complex dynamic situations. The use of eye-tracking metrics in a convergent manner constitutes a powerful tool to portray DDM and can contribute to DSS usability testing.

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