A Full-Mission Evaluation of A Computational Model of Situational Awareness

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ABSTRACT

Although use of the term situational awareness (SA) assists researchers in creating more fruitful environments for pilots to operate in, its true potential as a psychological construct remains untapped until a valid means of *a priori* predicting SA becomes available. Shively, Brickner and Silbiger (1997) proposed a computational model of SA (CSA) that seeks to do just that, and the current line of research is a series of studies aimed at validating that model. Originally developed for the Man-machine Integration Design and Analysis System (MIDAS), the CSA model is comprised of two features: situational elements and situation-sensitive higher-order nodes. Situational elements comprise what is known/perceived about the environment (e.g. *tank1* or *waypoint3*). Each is associated with a particular higher-order node, and as a group define the situation. Higher-order nodes are semantically related groups of SE's (e.g. *threats* or *navigation*) that are weighted based on their importance in the situation. One original aspect of the CSA model is the differentiation between *perceived*, *actual* and *error* SA, a proportion of which produces the operator's predicted SA. Initial validation studies using low-fidelity tasks supported the predictions of the model. Preliminary data analysis of a mid-fidelity, full-mission task completed in the Rotorcraft Part-Task Laboratory (RPTL) at NASA Ames also indicates support for predictions of the model.

Introduction

Computational Model of Situational Awareness

In an effort to accurately predict SA prior to a task and across environments, Shively, Brickner and Silbinger (1997) created a computational model of situational awareness. Initially conceived for the Man-machine Integration Design and Analysis System (MIDAS) (Smith & Tyler, 1997), the computational model of situational awareness is simply the ratio of the operator's relevant knowledge to the information needed for the mission task. Further, this model makes a distinction between actual, perceived and error SA.

Goal of Research

The goals of this line of research were threefold:

- To develop a computational, clearly defined, predictive model of SA.
- distinguish between perceived and actual SA.
- validate this model in simulation.

Situational Awareness Model

The SA model as currently instantiated in MIDAS is comprised of two essential features, situational elements and situation-sensitive nodes. These two features will be briefly described, but for a more detailed description of the model see Shively et al., 1997.

Situational Elements (SE's) are relevant information in the environment that define the situation. These include such things as other aircraft, obstacles, waypoints, ownship parameters, etc. The operator receives these elements mostly through perception; however, they are also received through paths such as experience or a pre-flight briefing. Each SE has a mathematical weight attached to it based on its importance in the situation. In addition to its weight, each SE has a mathematical value associated with it based upon one of four levels of awareness. The four levels of awareness (detection, recognition, identification, comprehension) are a quantification of the operator's perception of the SE.

Situation-sensitive nodes are semantically related collections of situational elements. The nodes are defined by what is important in the situation and are weighted by the overall importance of the node in determining the level of SA. Thus, in the current study; one node is *Navigation* and it is comprised of the SE's *flight path*, all the *waypoints*, *landmarks*, and the *accident site*. Because visual navigation is so important to the task, the weight on the node is .5. If the situation changes then the weights on the nodes, or the nodes themselves, may change to accurately reflect the ideal SA.

One original facet of the model is the differentiation of perceived, actual and error SA. Perceived SA is what operators work with…the level of SA they *think* they have. However, it may include errors in perception or identification. Error SA is a computation of SE's that are misperceived or misidentified. Actual SA is differentiated from perceived SA by including factors for unknown SE's in the computation and then subtracting the error component.

Course of research

A series of studies was conducted at NASA Ames Research Center in an attempt to validate this model and to see if the predictions of operator SA were equal to generally accepted measures of operator SA. Each of the three studies will be described.

Study 1 - Star Cruiser

The goal of the initial study was simply to test the hypothesis that situational awareness could be broken down into actual and perceived SA. Based on the assumption that the subjective SART measurement (Taylor, 1990) is a valid measure of perceived SA and that the objective SAGAT measurement (Endlsey, 1995) is a valid measure of actual SA, this study sought to show that operators can be induced to believe their SA is higher than it really is. 10 college students performed 7 trials on the Star Cruiser software program. Each trial required the participant to fly a simulated spacecraft through a galaxy and perform various mining and exploring tasks. After each trial half of the participants were told they were doing extremely well and the other half were given neutral feedback. Both SART and SAGAT were collected on each trial in addition to various performance measures. As can be seen from some of the results in Figure 1, as time progressed the perceived SA (SART SA) of the neutral group fell over time while the perceived SA of the positive feedback group rose. While these differences did not reach significance, the trends were in the predicted direction.

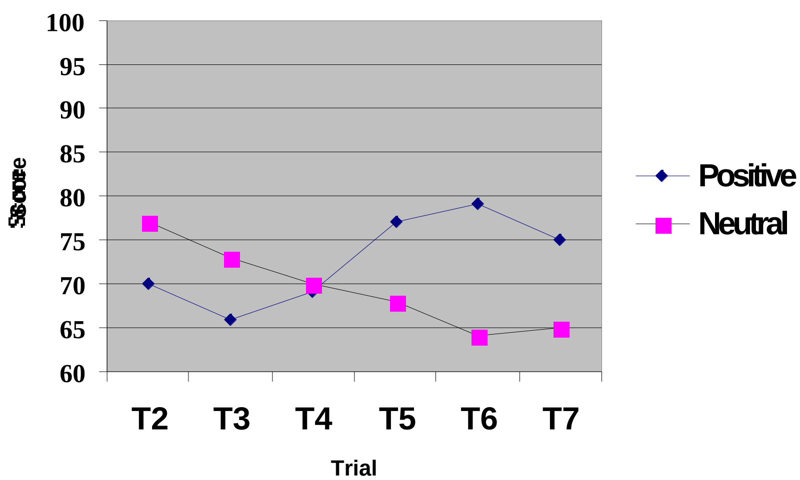

Figure 1. SART SA scores by function of trial order

Study 2 - Window/PANES

This study used the Workload/PerformANcE Simulation software (Window/PANES, NASA Ames Research Center, 1989) to create a low-fidelity cockpit simulation. The study was based on a one-way, (high predicted SA vs. low predicted SA) within-subjects design. Ten GA pilots completed six pairs of trials differing within pair only in the level of awareness for various situational elements making up three higher order nodes: Navigation, System Management and Flight Control. Table 1 indicates some of the results.

Table 1. Summary of SA measures

Measure	Pred High SA cond.	Pred Low SA cond.	Prediction Adherence
In Task (objective)			
Map related questions	22.4	17.5	Yes $p<.05$
Gauge related questions	24.0	21.1	Yes
Prompted waypoints	7.8	7.8	
Unprompted Waypoints	6.11	4.00	Yes $p<.05$
SART SA	80.87	74.74	Yes
Post Task (objective)			
Flight Path	90.6	83.2	Yes
Gauge Level error	14.7	15.7	Yes
Map questions	49.6	52.2	No

In general, the results of this experiment supported the predictions of the SA model. Subjective as well as performance measures of SA corresponded to the predictions. However, this was clearly not a strong test of the model. This effort in the validation of the model allowed for gross distinctions in SA, such as predicting high vs. low SA, but did not attempt to differentiate among moderate levels of SA or manipulate weightings on nodes. Predicting finer distinctions of SA requires a more sensitive instrument that allows pilots to apply their experience.

Current Study

The goal of the current study was to continue the experimental validation of the SA model created by Shively, Brickner and Silbiger. Specifically, we wanted to create a family of scenarios, differing only in the level of awareness of the situational elements, which would result in low, medium and high situational awareness predictions by the model. These predicted SA levels would then be compared to scores from a battery of accepted SA measures, such as SART and SAGAT, to see if the model was able to mathematically predict the scores.

Method

Participants and materials

Six general aviation pilots were trained on the new Rotorcraft Part-Task Laboratory (RPTL) at NASA Ames Research Center. This single-person, fixed-base simulator consists of an Out-The-Window view and Instrumentation Panel each displayed on high quality SGI viewers. Rotorcraft control is currently performed using a flybox that sits on the pilot's lap. A lever controls the collective movement and a joystick controls pitch, roll and yaw. Figure 2 displays the RPTL cab while Figures 3 and 4 display the Out-The-Window view and instrumentation, respectively.

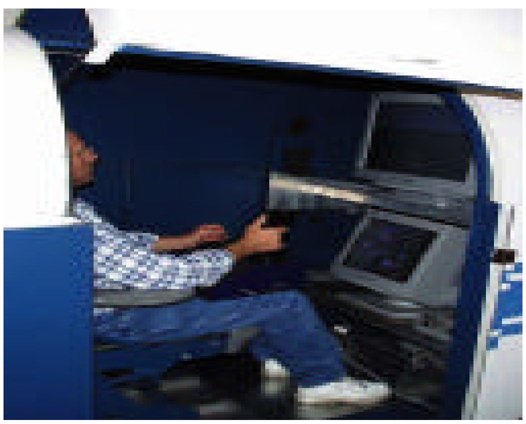

Figure 2. Rotorcraft Part-Task Laboratory (RPTL)

Figure 3. Out-the-Window view

Figure 4. Instrumentation

Design

The study was based on a one-way (predicted high, medium or low SA) within-subjects design. Each participant completed nine MEDEVAC scenarios consisting of ingress to an accident site followed by an egress to a pre-selected hospital or airport. Each scenario was repeated under three different experimental conditions that differed only in the level of awareness for various situational elements making up the task.

A task analysis performed on the scenarios, in conjunction with experienced MEDEVAC pilot input, determined the relevant situational elements for the task. These situational elements were analyzed and aggregated into three situation-specific nodes that were then weighted based on their importance in the scenario. Table 2 indicates the three nodes along with the computational weights and SE's associated with each node.

Table 2. Situation-specific nodes, weights and situational elements

NODE	WEIGHT	SITUATIONAL ELEMENTS
Navigation	.5	Briefed flight path, Waypoints, Landmarks, Accident site,
Ownship	.3	Airspeed, Radar altitude, Heading, V/S, Fuel quantity and Consumption rate, Engine and Oil temps, Percent torque
Air traffic	.2	Visible traffic bearing, Heading, Relative altitude

The three experimental conditions of predicted high, medium or low SA were created by manipulating the level of awareness of the various situational elements in the task. For example, in the conditions predicted to lead to high SA the situational element "briefed flight path" was a clearly defined flight path on a map given to the pilots. In the conditions predicted to lead to medium levels of SA, the SE was a lightly scribed flight path on the map. For the conditions predicted to lead to low SA the SE was a map with no obvious flight path inscribed on it. Table 3 lists the various manipulations performed on scenario variables that resulted in the three different experimental conditions.

Table 3. Manipulations resulting in three different experimental conditions

Manipulation	Pred High SA	Pred Med SA	Pred Low SA
Pre-trial briefing	Extensive	Moderate	Brief
Detail of map	Path, type, loc, hdg, time, divert	Faint path, loc, hdg, divert	No path, loc, time, divert
Visibility	CAVU	Hazy	Fog, < 1 mi vis
Contrast	High contrast	Good contrast	Poor contrast
Clutter	Isolated wp	Objects near wp	Clutter near wp
Air Traffic	Single, on legs	Single, near wp	Groups, near wp
Ownship instruments	Gauges easy to read	Gauges harder to read	Gauges difficult to read

After manipulation, the mathematical weights of all SE's were assigned based on the level of awareness of the situational element in each trial. Current values associated with the levels of awareness are .25, .50, .75, and 1.00 for Detection, Recognition, Identification and Comprehension, respectively. These currently are arbitrary linear values and subject to validation. Table 4 shows the calculations for a predicted High SA trial based on equal weighting of all the SE's within a node and with the node weights as described in Table 2.

Table 4. Calculations for a predicted High SA trial

Situational Element	Level of Awareness	VALUE	NODE
Flight Path	Comp	1.00	Nav
Waypoint1	Comp	1.00	Nav
Waypoint2	Ident	.75	Nav
Waypoint3	Ident	.75	Nav
Landmark1	Comp	1.00	Nav
Landmark2	Ident	.75	Nav
Site	Comp	1.00	Nav
Radalt	Ident	.75	Ownship
Airspeed	Comp	1.00	Ownship
Heading	Comp	1.00	Ownship
Aircraft1	Comp	1.00	Aircraft
Aircraft2	Ident	.75	Aircraft
Aircraft3	Ident	.75	Aircraft

Predicted SA = [((1.00+1.00+.75+.75+1.00+.75+1.00)/7)*.5] + [((.75+1.00+1.00)/3)*.3] + [((1.00+.75+.75)/3)*.2] = .45 + .28 + .17 = **.9**

It should be mentioned that the value for predicted SA in this trial is the same for both the actual and perceived SA values. This study included no misrepresentations or errors that would work to separate the two values.

Procedure

Pilots were required to be present for three hours on two consecutive days. Two hours of the first session and the first 30 minutes of the second session were given over to training on the RPTL simulator. Training scenarios were designed to acquaint the pilots with handling characteristics of the rotorcraft and to expose them to such factors as rate of turn, acceleration, route following and to maximize exposure to low level flight.

Before each experimental scenario, each pilot was given an enlarged sectional map of the database area along with a set of text instructions detailing route specifics. A preflight briefing was conducted that described the route, waypoints, landmarks, headings, time between waypoints and total time. Pilots were instructed to fly at an airspeed of 80 to 120 knots and an altitude above ground level of 200 to 400 feet. Moreover, they were to verbally contact the experimenter when they saw any other air traffic during the flight and relate the traffic's type, relative bearing, heading and relative altitude.

Pilots were briefed that at some point during each ingress/egress, the simulator would pause and SAGAT probes would appear on the instrumentation panel. Responses to these probes were verbal and recorded by the experimenter. After each ingress/egress leg, the simulation ended and the pilots were given a four-dimensional SART survey, followed by a post-task questionnaire.

Results

Preliminary data analysis indicates the predictions of the model were borne out. Figure 5 shows the SA component of the SART survey as compared to the model's predictions of the perceived SA across experimental conditions. The slower than expected rise in perceived SA as measured by SART can possibly be attributed to a ceiling effect owing to the difficulty of the task, even under optimal conditions.

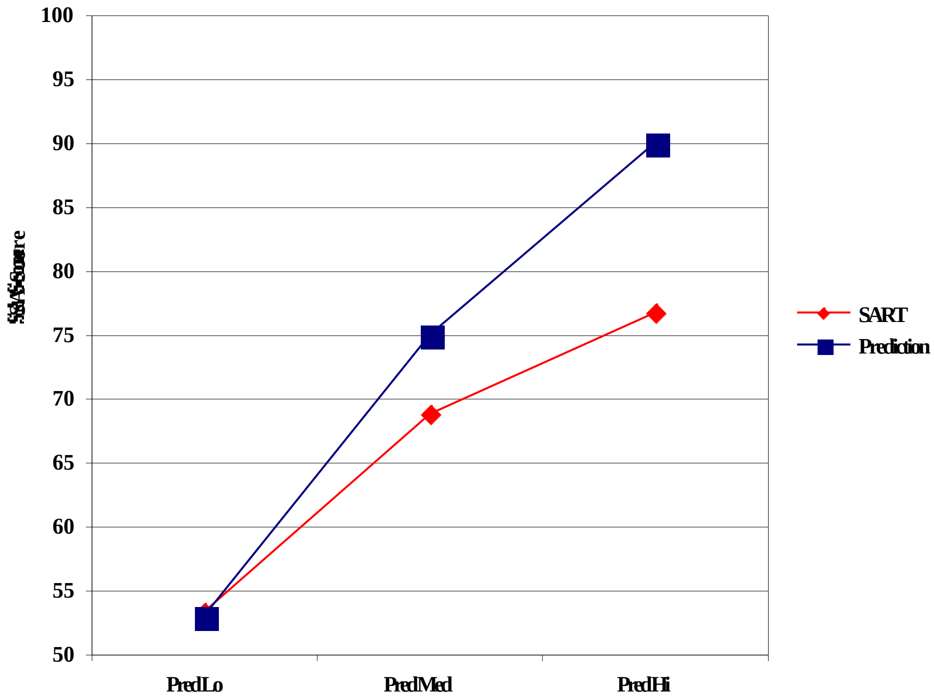

Figure 5. SART SA and Predicted SA as a function of condition

Figures 6 and 7 are two measures taken from the SAGAT probes administered on each half of every trial. SAGAT Heading displays the mean error in degrees when pilots were asked their current heading. SAGAT AGL displays the mean error in feet between pilot estimate of current altitude above ground level and actual altitude above ground level. As can be seen from the figures, the actual SA levels, as measured by various SAGAT probes, are in the predicted direction. The sole exception to this is the heading error in the medium condition.

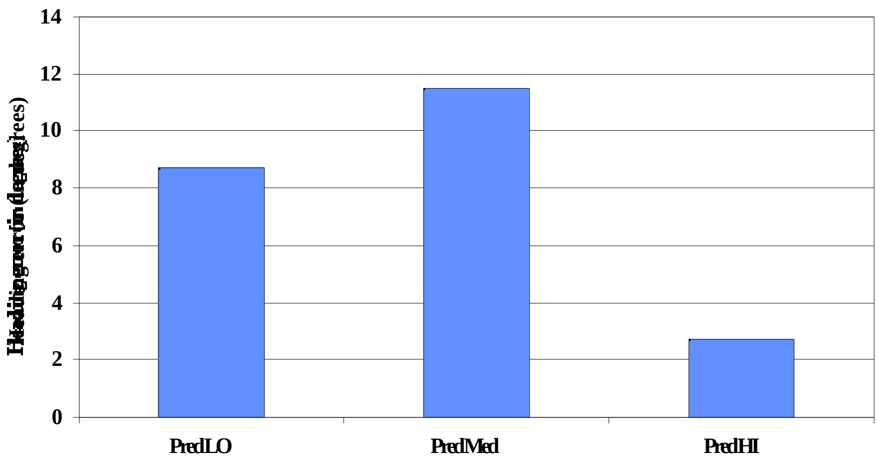

Figure 6. SAGAT Heading as a function of condition

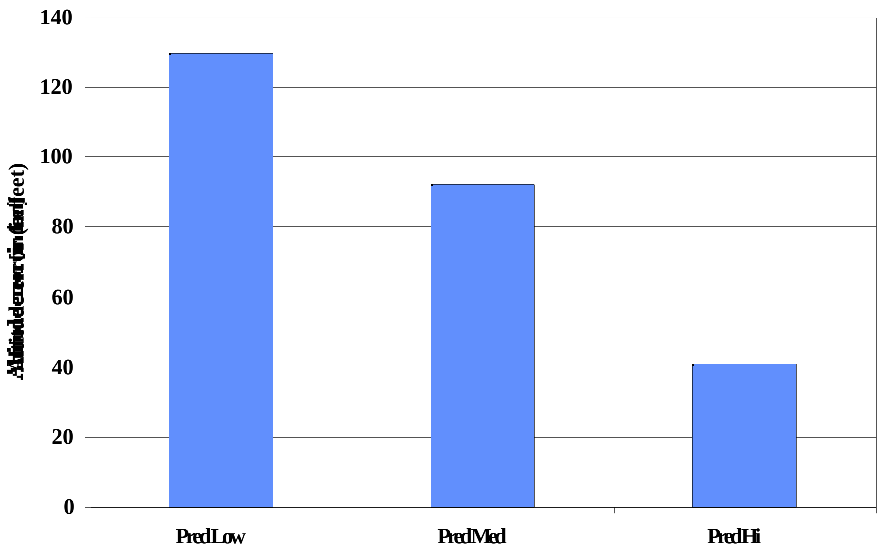

Figure 7. SAGAT AGL as a function of condition

Summary

Although the data analyzed indicate support for the predicted SA as computed by the model, it must be mentioned that these results are still preliminary results. Further SA measures are forthcoming from post-task questionnaire analysis and from correlations with various performance measures taken during the trial. Overall however, this model appears to be valid for *a priori* computing SA in a given situation. Future diagnostic testing of the model using actual MEDEVAC pilots, control inceptors and true in-flight communications will allow for a more stringent test of the model's predictions. Furthermore, the introduction of erroneous information will allow model's differentiation of perceived, actual and error SA to be tested.

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