2013

Exploring the Effects of Working Memory Capacity, Attention, and Expertise on Situation Awareness in a Flight Simulation Environment

Orçun Orkan Özcan

Murat Perit Çakır

Bilge Say

EXPLORING THE EFFECTS OF WORKING MEMORY CAPACITY, ATTENTION, AND EXPERTISE ON SITUATION AWARENESS IN A FLIGHT SIMULATION ENVIRONMENT

Orçun Orkan Özcan, Murat Perit Çakır, and Bilge Say
Department of Cognitive Science, Middle East Technical University, Ankara, Turkey

Simulator pilots are subject to some of the constraints of a real flight situation in a PC based flight simulation. Situation awareness (SA) for simulator pilots was explored in terms of underlying cognitive aspects by analyzing the compound effects of expertise, working memory, inhibition and divided attention. Online and Offline SA measurements were analyzed with expertise and scores of Automated Operation Span Task, Stroop and Coşkunöz visual attention tasks. Regression analyses revealed the expected relationships of simulator pilots' SA with expertise and inhibition capacity but not with working memory and divided attention capacity. Obtained results were also compared to those of professional pilots. Despite similar cognitive capacities and expertise, simulator pilots had incompatible results with professional pilots in offline SA queries and they exhibited different SA performance related to expertise and cognitive capacity tests. This situation probably resulted from unsystematic differences in simulator pilots' practices.

The construct of Situation Awareness (SA) is a quite rigorous term standing for composition of many psychological abilities. Considering the cognitive aspects of the phenomenon, it can be seen that SA has been associated with several abilities like perception, long-term memory, working memory, attention, reasoning, and decision-making (Horswill and McKenna, 2004; Breton and Rousseau, 2001; Endsley, 1995b, 1997). However, the current status in the literature on SA does not converge to a well-defined combination of these abilities. This situation motivates a need for cognitive elaboration in order to clarify SA's components as a complex cognitive phenomenon. The cognitive components of SA were described by a limited number of studies (Durso & Gronlund, 1999; Endsley, 1995b; Sarter & Woods, 1991; Wickens, 1999) and individual differences in SA memory requirements were studied by few researchers (Carretta, Perry & Ree, 1996; Johannsdottir, 2004; Sohn & Doane, 2004). However, in most cases, the experimental designs of these studies either lack an explicit assessment of SA in the task environment or do not involve operators/ pilots as participants. Consequently, further explorations are needed for the cognitive grounding of SA. A recent study on this area has been conducted by Serkan Çak (2011) where 36 professional pilots were subjected to SA and cognitive capacity tests. In the current study, the flight scenario, SA queries and cognitive capacity tests from Çak (2011) were used for simulator pilots with modifications (Özcan, 2012). The research motivation was to find out the possible differences in the cognitive contributions to SA between professional and simulator pilots, who were not pilots but have been trained and experienced in PC based flight simulator environment.

Method

The experimental setup used in the study consisted of a simulated flight task, AOSPAN, Stroop and Coşkunöz visual attention tests for measurement of SA, working memory capacity, and inhibition and divided attention capacities, respectively. In order to have comparable results between professional and simulator pilots, this study was based on Çak's doctoral studies (2011) and similar experiments, except for divided attention, with modifications were used. The original flight scenario has been modified for simulator pilots together with expert simulator pilots who worked as Subject Matter Experts (SME). Multimodal divided attention task was changed with a only visual task because simulator pilots do not use radio extensively and they don't pay considerable attention to auditory modality. For this reason, Coşkunöz visual attention test was introduced. Detailed information and modifications on the original scenario can be found in Özcan (2012).

Participants

For the behavioral experiments, thirty five simulator pilots (all male) with a moderate to an advanced experience level participated. They were selected through online simulation communities after completing a pre-flight scenario at home. Simulator pilots who also have professional piloting experiences were not accepted in the study[1]. Details of the pre-flight scenario can be found in Özcan (2012). All participants were native speakers of Turkish. Their mean age was 30.7 and their average total flight hour was 1356[2].

Design

The Simulated Flight. In the first task, participants were asked to perform a simulated flight as a pilot for Cessna-172 fixed wing aircraft in Microsoft Flight Simulator 2004 environment. During the flight several uncommon events occurred. Questions about the current status of flight were asked for an assessment of the participant's situation awareness (SA). Similar to the original scenario from Çak (2011), for a cognitively demanding scenario, simulation duration was planned as 75 minutes. The take-off and climb phases were designed to be standard and required a low workload demand for familiarization at the beginning of the experiment. However, after the first 25 minutes, the weather became worse and several equipment failures should have resulted in an increased workload for cruise, descent and approach phases of the flight. The original scenario was retained in terms of novel events experienced during the flight. The novel events were icing, rain, turbulence, crosswind, low visibility, low ceiling and planned failures in the equipment (VSI, RMI/HSI Compass, and ASI). The motive was to introduce high workload and stress, which reveals cognitive differences among participants. Queries were administrated with SPAM technique (Durso and Dattel, 2004) for eight online measurements and with SAGAT technique (Endsley, 1995a) for thirteen offline measurements. The original SPAM technique was modified by removing the "reject to answer" option in order to assure high workload during the SA queries (Çak, 2011). Online queries were carried out orally while offline queries were asked in two sessions, with five and eight questions at a time. Further details of the scenario can be found in Özcan (2012).

AOSPAN. For an assessment of working memory capacity, the Automated Operation Span (AOSPAN) test was used (Unsworth et al., 2005). This test is the computerized version of operation span task (Turner & Engle, 1989) and taps on complex working memory. For this task, three to eight letters are shown in a sequence to be remembered. Participants also have to correctly answer 85 % of mathematical questions asked before each letter. After the eight-letter sequence is recalled, the score is calculated as the sum of perfectly remembered sequences through the task. No ceiling effect was observed despite highly qualified participants. It has been administrated using E-prime software (Psychology Tools Inc.) and details of the procedures for AOSPAN task can be found in Unsworth et al. (2005).

Stroop. To measure inhibition capability in attention, the Stroop task, an indicator of well-managed attention (MacLeod, 1991), was used. The task was based on the ability of inhibiting a habitual response in favor of the goals of the task. Inhibition came into play where participants had to suppress the prepotent response, word reading, in favor of color naming. The difference in response times between congruent and incongruent cases was calculated as the inhibition delay as commonly used in the literature (MacLeod, 1991). In response time calculation, any wrong color namings have been excluded. This task has also been administrated using E-prime software.

Coşkunöz Visual Attention Test. Divided attention was measured by a dual visual task, Coşkunöz Visual Attention Test developed by Er, Sümer, Koku, Mısırlısoy, Coşkan, Erol-Korkmaz, Sümer, Ayvaşık and Eriş (2011) in which participants were expected to follow and respond to two visual tasks running at the same time on the left and the right sides of the screen. On the left side, a red dot traveled through the borders of a hidden shape without leaving a trace. When it was finished, participants were asked to find this shape among five alternatives. On the right side, four drawings of a tool were presented, one of which was slightly different. The different one was expected to be selected. The task on the left side can be considered as the primary task, since, as it runs, the task on the right side (the secondary task) runs for 5 to 7 times. The divided attention capability was measured by the combined score which is the number of the correct answers for the secondary task that were answered in the period where the primary task was correctly answered.

---

[1] One participant working as a professional Air Traffic Controller and two participants who were student pilots participated in the study. Data from these participants were not found to be outliers.

[2] Total flight time for simulator pilots include piloting experiences from different platforms.

Results

Individual Cognitive Differences and Situation Awareness

Table 1.
Correlations between variables

Variable	1	2	3	4	5	6	7
1. Online SA Score							
2. Online RT	.01						
3. Offline SA Score	.20	-.28					
4. Combined SA Score	**.72***	-.19	**.82***				
5. Working Memory	.01	.24	-.00	.00			
6. Inhibition	-.31	**.50***	**-.55***	**-.57***	.27		
7. Divided Attention	.03	-.10	.12	.10	.16	-.22	
8. Log (Expertise)	.14	-.22	**.49***	**.43***	.08	-.27	-.02

Note. N = 35, * p <.01

Online SA Reaction Time (RT) values have been obtained by summing up RTs for successfully answered online queries. Combined Score was the summation of Offline and Online SA scores. Individual cognitive differences were represented by scores from AOSPAN, Stroop and Coşkunöz visual attention tasks. For expertise, participants' total flight time on several simulation platforms have been used.

For the purpose of finding contributions of predictors to SA measures, expertise, working memory, inhibition and divided attention capacity scores have been used in linear multiple regression analyses. Four regression analyses for Offline SA, Online SA, Online RT and Combined SA have been done on SPSS (Version 20) using data from thirty-five participants. Obtained data has been analyzed for descriptive statistics first. Due to the non-linear relations observed between expertise and dependent variables, log transformation is applied on expertise values.

Correlation analysis has been performed to see the connections between the variables as given in Table 1. Combined scores have significant correlations with Online and Offline Scores since it is calculated as a sum of the two. Online RT, Offline and Combined Scores are significantly correlated with one of the predictors, inhibition capacity and Offline and Combined SA Scores are significantly correlated with expertise. Correlations between SA scores and inhibition capacity are negative since inhibition delay represents the delay in the incongruent cases in Stroop task. Among the predictors, no correlation has been found.

Considering the results from regression analysis, situation awareness is associated with only inhibition capacity and expertise for simulator pilots. Working memory and divided attention capacity were not found to be predictors for any SA measurement.

Comparison with Professional Pilots

As mentioned before, similar tasks from Çak's study with professional pilots have been carried out with simulator pilots and comparable results have been obtained. For professional pilots, 58% of variability in offline SA measures was accounted for by variances in working memory and expertise measures (Çak, 2011). In Çak's analysis, WMC was the most successful predictor (β = .675, t(31)= 5.31, p<.00), whereas the other predictor, expertise (β = .278, t(31)= 2.35, p<.05) was not that successful. For online SA measures (average RTs for correct answers in online queries), 52% of variability was accounted for by variances in inhibition, divided attention and expertise measures. The predictors in order of strength are listed as expertise (β= -.470, t(31)= -3.73, p<.001), divided attention (β= .313, t(31)= 2.25, p<.05) and inhibition (β = .260, t(31)= 2.058, p<.05). However, for simulator pilots inhibition capacity and expertise were found to predict online and combined measures of SA while working memory and divided attention capacities were not predictive. Further results from the regression analyses can be found in Table 2. In comparison to the preceding study carried with professional pilots (Çak, 2011), results from the current study did not reflect a clear picture of a cognitive grounding for SA especially for individual cognitive differences in working memory and divided attention capacities.

Table 2.
Regression Results for SA measurements.

		Predictors			
Dependent Variable	Regression Result	Inhibition	Log (Expertise)	Working Memory	Divided Attention
1. Online SA Score	Not successful	-	-	-	-
2. Online RT	adjusted R^2 of .17 (F(4,34) = 2.756, p= .05)	β = .434, t(30)= 2.481, p< .05	-	-	-
3. Offline SA Score	adjusted R^2 of .38 (F(4,34) = 6.233, p< .01)	β = -.495, t(30)= -3.270, p< .005	β = .372, t(30)= 2.649, p< .05	-	-
4. Combined SA Score	adjusted R^2 of .36 (F(4,34) = 5.732, p< .005)	β= -.545, t(30)= -3.536, p< .05	β = .297, t(30)= 2.077, p< .05	-	-

Note. N = 35

Obtained results from the two groups were compared using independent group t-tests. Results showed that there are no significant differences between groups except for the Offline SA scores. Offline SA scores from professional pilots (M=720.37, SD=195.8) and simulator pilots (M=602.86, SD=166.6) were significantly different from each other; t(68)=2.704, p<.01. Further details of the statistical analysis can be found in Özcan (2012). Despite the similarities in cognitive capacity tests and expertise, professional pilots were distinctively more successful in offline SA queries[3]. The differences in pilot training backgrounds and practice systems structures are candidate reasons to explain this finding.

Discussion

Considering the whole regression results obtained for simulator pilots, first unexpected finding is the absence of expertise as a consistent predictor. The regression results report that expertise contribute to the explanation of the variances in only Offline SA and Combined SA scores. Leaving the theoretical problems of measuring SA aside, the first reason is possible errors in assessment of expertise. In Çak's studies, professional pilots' expertise was determined as the number of flight time spent in the specific full flight simulator, not of the actual flight. For simulator pilots, their total simulation flight time from different platforms were used due to to the variety in their simulator experiences. As a result, this assessment technique for expertise comes with precautions for its contribution to the prediction of SA measurements. Another important issue for this study is that WMC is found to be not explaining any of the variances in the SA measurements. Working memory is considered to have a central importance for SA (Durso & Gronlund, 1999; Endsley, 1995b). Flight critical tasks, systems and timely information are kept and processed by working memory (Wicken, 1999). Also, there are several studies in which the correlation between SA measures and WMC is given (Durso et al., 2006; Gonzales and Wimisberg, 2007). However, in this study, no correlations or similarities in variances has been observed between WMC and SA measures. A possible explanation to this finding is the vast range of differences in simulator piloting practices

[3] Online SA scores between professional and simulator pilots could not have been compared since in Çak's study only online SA reaction times were measured.

compared to professional piloting. Simulator pilots are generally self-educated and have their own unique ways of piloting due to the lack of formal education. During the experiments, it is observed that they learn simulator piloting with the help of autopilots and automatic navigation devices. Overall considerations on the results point that differences between professional and simulator pilots are more foundational than expected and simulator pilots' performances on SA measurements are not determined by the systematical factor of working memory capacity, but possibly determined by individual self-training differences.

Following the discussion on lack of a formal education, the results for the rest of predictors, inhibition and divided attention seem to lose their importance. However, even under these considerations, it is important to note that inhibition capacity happened to be the consistent predictor for Online RT, Offline and Combined SA measurements. Attention control capability captured by Stroop task, unlike utilization of working memory for elements of flight, is found to be effective in SA performance. Since the SA measurements were carried out as the participants were busy with piloting, answering these queries required a successful management of attention. Possibly with this connection, inhibition capacity turned out to be a consistent predictor. Along similar lines, the reason why divided attention did not turn out to be a good predictor can be explained. Compared to the real flight situation, simulation environment is simple in terms of environmental factors. Simulation environment consisted of a PC and a joystick while real flight contains two environments, the cockpit and the outside of the airplane. Professional pilots observe both the equipments inside the plane and weather conditions outside the plane. Consequently, it might be proposed that divided attention capacity for simulator pilots is not as important as it is for professional pilots. Nevertheless, due to the effects of unsystematic differences in simulator pilots' practices as mentioned above, these comments have to be interpreted with caution.

Acknowledgements

Authors gratefully acknowledge contributions from Dr. Serkan Çak, Dr. Mine Mısırlısoy, Dr. Canan Sümer, her team in METU Psychology Department and the Coşkunöz Metal Forming Company. Authors also thank THK Antalya Branch members for their organizational support and simulator pilots for their participation. This paper is based on the Master Thesis of the first author (Özcan, 2012).

References

Breton, R., & Rousseau, R. (2001). *Situation awareness: A review of the concept and its measurement* (Technical Report No. 2001-220). Valcartier, Canada: Defense Research and Development.

Carretta, T. S., Perry Jr., D. C., & Ree, M. J. (1996). Prediction of situational awareness in F-15 pilots. *The International Journal of Aviation Psychology,* 6(1), 21-41.

Çak, S. (2011). *Effects of working memory, atention, and expertise on pilots' situation awareness.* Unpublished doctoral dissertation, the Middle East Technical University, Ankara.

Durso, F. T., Bleckley, M. K., & Dattel, A. R. (2006). Does situation awareness add to the validity of cognitive tests? *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 48(4), 721-733.

Durso, F. T. and Dattel, A. R. (2004). SPAM: The real-time assessment of SA. In S. T. S. Banbury, editor, *A Cognitive Approach to Situation Awareness: Theory, Measures and Application* (pp.137–154). Ashgate.

Durso, F. T., & Gronlund, S. D. (1999). Situation awareness. In F. T. Durso, R. Nickerson, R. Schvaneveldt, S. Dumais, S. Lindsay, & M. Chi (Ed.), *The handbook of applied cognition* (pp.283–314). Wiley.

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 37(1), 65–84.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 37(33), 32-64.

Endsley, M. (2006). Expertise and situation awareness. In K. A. Ericsson, N. Charness, P. Feltovich, & R. Homan, (Eds.), *The Cambridge Handbook of Expertise and Expert Performance,* (pp.636–651). New York: Cambridge University Press.

Endsley, M. (1997). The role of situation awareness in naturalistic decision making. In C. Zsambok and G. Klein, (Eds.), *Naturalistic Decision Making*, (pp.269-283). Lawrence Erlbaum Associates.

Endsley, M. R., & Bolstad, C. A. (1994). Individual differences in pilot situation awareness. *International Journal of Aviation Psychology,* 4(3), 241-264.

Er, N., Sümer, H. C., Koku, B., Mısırlısoy, M., Coşkan, C., Erol-Korkmaz, H. T., Sümer, N., Ayvaşık, H. B., & Eriş, A. (2011). *Çoşkunöz visual attention test.* Unpublished instrument.

Gonzalez, C., & Wimisberg, J. (2007). Situation awareness in dynamic decision making: Effects of practice and working memory. *Journal of Cognitive Engineering and Decision Making,* 1(1), 56-74.

Horswill, M. S., & McKenna, F. P. (2004). Drivers' hazard perception ability: Situation awareness on the road. *A cognitive approach to situation awareness: Theory and application*, 155-175.

Johannsdottir, K. R. (2004). Situation awareness and working memory: *An integration of an applied concept with a cognitive fundamental process.* Unpublished doctoral dissertation, Carleton University, Ottowa.

Macleod, C. (1991). Half a century of research on the stroop effect: An integrative review. *Psychological Bulletin,* 109, 163-203.

McCarley, J. S., Wickens, C. D., Goh, J., & Horrey, W. J. (2002). A computational model of Attention/Situation awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* 46(17), 1669-1673.

Özcan, O. O. (2012). *Exploring the Effects of Working Memory Capacity, Attention, and Expertise on Situation Awareness in a Flight Simulation Environment.* Unpublished master's thesis, the Middle East Technical University, Ankara. Retrieved from https://dl.dropbox.com/u/14641303/Ozcan_MSc.pdf.

Sarter, N. B., & Woods, D. D. (1991). Situation awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology,* 1(1), 45-57.

Sohn, Y. W., & Doane, S. M. (2004). Memory processes of flight situation awareness: Interactive roles of working memory capacity, long-term working memory, and expertise. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 46(3), 461-475.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language,* 28(2), 127-154.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Enle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods,* 37(3), 498-505.

Wickens, C. D. (1999). Cognitive factors in aviation. In F. T. Durso, R. S. Nickerson, R. W. Schvaneveldt, S. T. Dumais, D. S. Lindsay, & M. T. H. Chi (Eds.), *Handbook of Applied Cognition* (pp. 247–282). Wiley.